Display Glass Requirements for Oxide TFT Technology

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ABSTRACT

The display industry continues to push the limits of size and resolution for high-performance tablets, notebooks and 8K TVs. As these trends become industry standards, the oxide market emerges as an important opportunity for enabling the next-generation of high-performance displays. These displays feature: higher resolution and faster refresh rates; enhanced circuitry integration to achieve slim bezels; and cost savings for panel makers by improving the panel aperture ratio and enabling large gen size manufacturing.

To achieve these technical requirements, new breakthroughs are needed in thin-film-transistor (TFT) technologies. Among the display industry's current offerings, amorphous silicon TFT (a-Si TFT) maintains a leading position among all applications, while low-temperature poly-silicon TFT (LTPS) is the predominant display technology for enabling high-performance handheld displays. The key differences between a-Si and LTPS are that an a-Si TFT has a simpler process, structure, and is easier to scale up in terms of manufacturing. However, LTPS offers better TFT performance to achieve higher resolutions and lower power consumption. The drawbacks of LTPS come in size limitations and increased manufacturing costs. For these reasons, neither a-Si nor LTPS can fully meet the technical requirements for this next generation of high-performance displays.

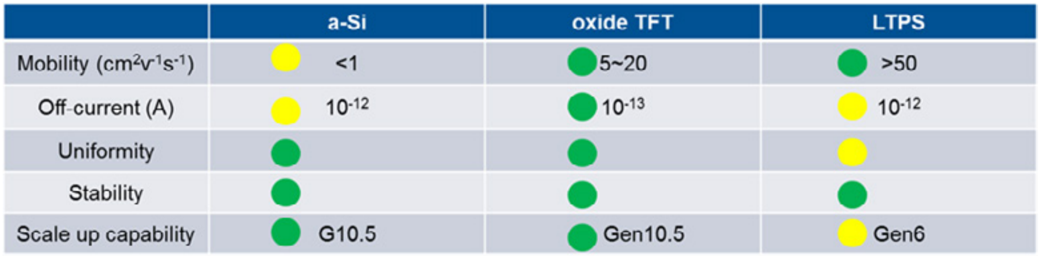
As a result, an industry need has arisen for oxide TFTs, an advanced, scalable high-performance TFT display technology that meets consumer demand for brighter, faster, more lifelike images. To meet these cost and performance expectations, oxide TFT panel makers need an advanced, thermally and dimensionally stable glass to improve yields while achieving the desired resolution.

OXIDE TFT TECHNOLOGY INTRODUCTION

For decades, the dominant technology for flat panel displays has been an amorphous silicon (a-Si) backplane. The vast majority of displays were made using a-Si backplanes due to the relative simplicity in the manufacturing process, attractive economics, and scalability to larger gen sizes. As demand for handheld devices with brighter and/or higher-resolution displays grew, alternative backplane technologies, such as low temperature polysilicon, became more prevalent. LTPS is similar to a-Si, but requires higher processing temperatures and a more complicated manufacturing process. The property requirements for the backplane are driven by pixel density and brightness. LTPS technology enables a backplane that meets those requirements. While LTPS has clear performance advantages compared to a-Si, the higher temperatures and more complex manufacturing process make LTPS considerably more cost-prohibitive than a-Si. Additionally, LTPS is not as easily scaled to larger sizes, limiting potential improvement to panel economics. Ideally, a backplane technology would combine the simplicity, economics, and scalability to larger panel sizes of a-Si with heightened performance closer to LTPS. Oxide TFT technologies bring the industry much closer to this ideal state. Indium-Gallium-Zinc-Oxide or IGZO is the most commonly used oxide semiconductor for oxide TFT backplanes.

Though the mobility of oxide TFT is not as high as LTPS, it is an order of magnitude better than a-Si technology and capable of driving OLED displays and 8K LCD TVs at 120Hz or higher. Additionally, the low off-current of an oxide TFT could enable low refresh frequency without flicker effects on static images. (A comparison of the three different TFT technologies is shown in Table 1.) Like LTPS, oxide TFT backplanes have improved electrical properties relative to a-Si backplanes, but oxide TFT backplanes can scale up to Gen 10.5 at reasonable costs (unlike LTPS), thereby enabling high-end, large-size LCD and OLED TVs. It is for this compromise of a-Si and LTPS properties that oxide TFT is garnering attention from panel makers worldwide. It offers the ability to manufacture advanced displays at sizes and costs that are today inaccessible for LTPS.

Table 1



	a-Si	oxide TFT	LTPS
Mobility ($cm^{2}v^{-1}s^{-1}$)	🟡 <1	🟢 5~20	🟢 >50
Off-current (A)	🟡 10^{-12}	🟢 10^{-13}	🟡 10^{-12}
Uniformity	🟢	🟢	🟡
Stability	🟢	🟢	🟢
Scale up capability	🟢 G10.5	🟢 Gen10.5	🟡 Gen6

OXIDE TFT PROCESS

There are two major oxide TFT processes to consider: etch-stop and back-channel etch (BCE). The key difference between the processes is the use of an etch-stop layer (ESL) that is required to protect the IGZO channels during the etching process.

ETCH-STOP LAYER OXIDE TFT PROCESS

Oxide TFT reliability was the major concern in the early stage of oxide TFT development. The oxide TFT channel was usually damaged in subsequent processes, so an etch-stop structure was designed to protect the oxide TFT channel. The ESL oxide TFT manufacturing process begins with a bottom gate structure which is covered by a gate insulator and TFT islands. After the gate insulator (GI) layers and TFT patterning, a patterned SiO2 layer is deposited to cover the IGZO channel area in order to protect oxide TFT during source/drain (S/D) etching. This enables better TFT reliability, and after the S/D etching, then followed by passivation, ITO layer as Figure 1 shows. In the ESL process, temperatures may go up to 300-400°C for up to an hour or more. While these are higher temperatures than some a-Si processes, it is considerably lower than the typical LTPS processes, which can exceed 500°C.

BACK-CHANNEL ETCH OXIDE TFT PROCESS

The BCE oxide TFT process (Figure 2) is similar to the ESL oxide TFT process in the first two photo etching processes (PEP) steps. However, a high-temperature (400-500°C) annealing process enhances the TFT reliability that allows the removal of the ESL. The higher temperature annealing step requires a thermally stable glass that can withstand harsh manufacturing environments and processing times relative to the conventional oxide ESL or a-Si processes. To panel makers, the BCE oxide TFT process is similar to the a-Si process, which has been widely used for the past two decades. Also, there is one photo-mask process reduction compared to the ESL oxide TFT process, therefore, BCE oxide TFT is becoming a mainstream process of oxide TFT manufacturing.

Figure 1

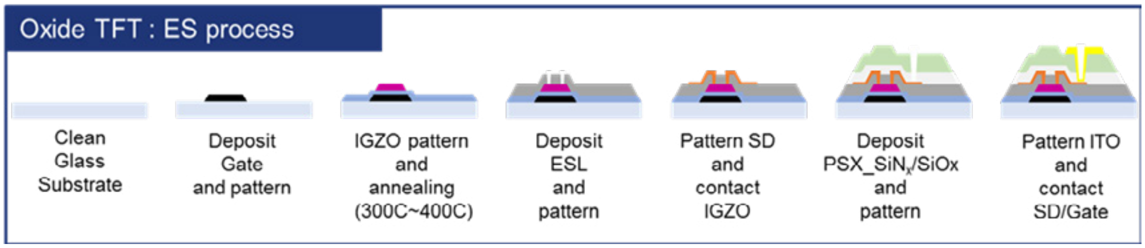


Figure 2

CHALLENGES FOR GLASS SUBSTRATES USED IN THE OXIDE TFT PROCESS

While the oxide TFT process has clear technical benefits for the manufacture of large and high-performance TVs, it presents a unique set of challenges for the glass substrate used in the process.

When put through a typical TFT backplane process, glass substrates will change shape or size (i.e., strain) which is called a change in total pitch (TP). One of the most important glass substrate attributes is total pitch variation (TPV), which is the deviation from predictable glass movement within a glass sheet and from sheet to sheet. For a glass substrate to have good TPV performance, the substrate must have the required balance of physical properties to resist the various causes of strain of the substrate: elastic distortion, stress relaxation, and compaction. For optimized TPV performance, a glass composition should feature a balance of these physical properties; sacrificing any one of these values to increase another would result in a less optimal composition. These sources of strain, and the corresponding glass property that resists them, are discussed below.

ELASTIC DISTORTION

In TFT processes, there are several sources of stress applied to the glass substrate, such as film stresses and gate metals. In oxide TFT, the latter is particularly significant due to the substantial thickness and covered area of the gate metal. The pitch change associated with these stresses is determined by the size of the stress, the elastic modulus of the glass, and the thickness of the substrate. Since the stresses are determined by the TFT manufacturer and the industry is continually driving to thinner and thinner substrates, the only attribute within the control of the glass manufacturer is to increase the elastic modulus to increase the stiffness of the substrate. Also, because the stresses in the TFT process can vary across a sheet or sheet-to-sheet, a high elastic modulus (i.e. higher than 80 GPa) will reduce the strain due to variations in the applied stresses, thereby minimizing TPV from this potential cause.

STRESS RELAXATION

The stresses from applied films and gate metal can also contribute to the overall TPV through the relaxation of those stresses during subsequent thermal treatments. As the substrate progresses through the various steps of the TFT process, the films, gate metal, and substrate itself will all undergo stress relaxation. As the stress state of the composite changes with time and temperature, the concomitant strain will accordingly change, causing a pitch change and an increase in TPV. The glass substrate resists this stress relaxation in proportion to its effective viscosity at the process temperatures. In a-Si TFT processes, the temperatures are low enough that there is a minimal amount of stress relaxation due to the glass substrate having a relatively high viscosity at these low temperatures (the viscosity of the glass increases as the temperature decreases). In oxide TFT processing, however, temperatures are higher and, therefore, the potential for stress relaxation is greater due to the lower effective viscosity of the glass. This is particularly acute for the BCE oxide TFT process, which has process steps with temperatures in excess of 400°C. Traditional glass substrates that are sufficient for typical a-Si applications may also be sufficient for the lower temperature ESL oxide TFT processes. However, the higher temperature BCE oxide TFT process may require a substrate with a higher effective viscosity at temperatures in the range of 400°C.

COMPACTION

The effective viscosity of the glass substrate also plays a role in the amount of viscous relaxation the glass substrate undergoes in the TFT process due to structural relaxation of the glass itself. This is commonly referred to as “compaction” or “shrinkage” in the glass industry. Compaction is due to the evolution of the glass structure from a non-equilibrium state toward a structure closer to equilibrium with the customer process. The amount of this viscous relaxation that occurs is proportional to the degree to which the glass is out of equilibrium, and inversely proportional to the effective viscosity of the glass at the TFT process temperatures. Consequently, a higher-viscosity glass is beneficial for minimizing TPV, just like in stress relaxation. In glass property terms, a higher-viscosity glass is a glass with a higher “annealing point;” therefore, glass manufacturers will often highlight the high annealing point of their glass compositions.

SAG

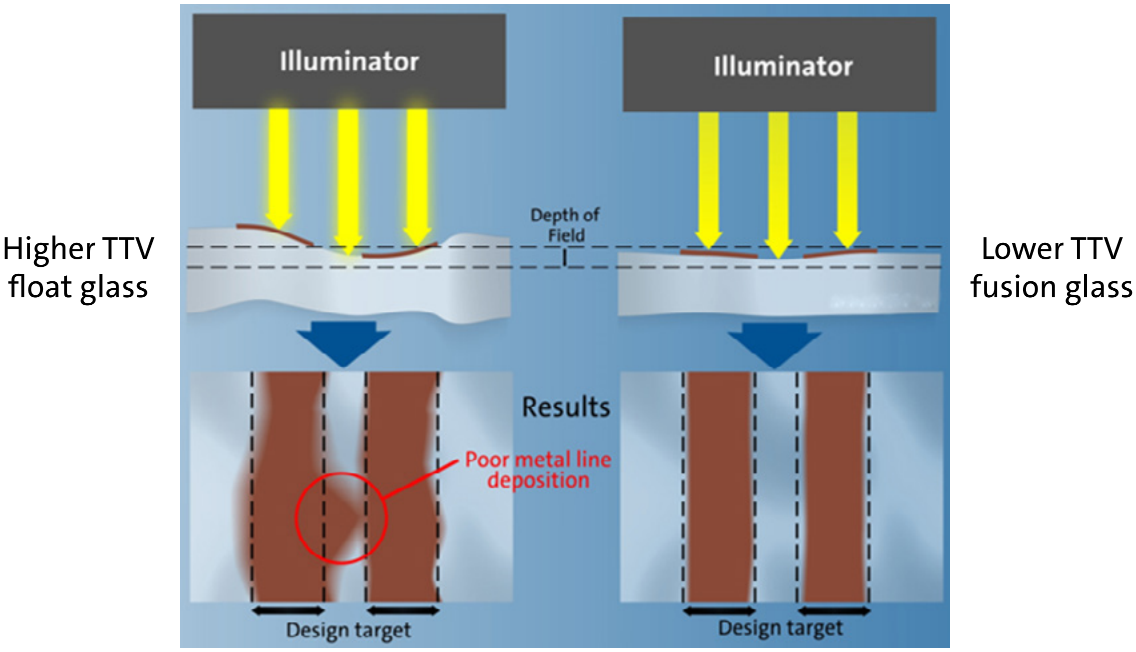
Glass sag typically occurs when a large sheet of glass is supported horizontally by its edges and allowed to naturally bend due to its own weight. Sag increases the process challenges on larger glass handling and uniformity in the OLED evaporation process. The amount of this sag is proportional to the glass density and inversely proportional to the elastic modulus. The elastic modulus represents the glass’s capability to resist deformation in the manufacturing process, while low density allows for a lightweight sheet of glass. This ratio of elastic modulus and density determines the amount of sag in the glass, with a higher ratio (higher modulus and/or lower density) leading to less sag and better performance.

TOTAL THICKNESS VARIATION

Measured in microns, total thickness variation (TTV) is variation of the glass thickness over a defined area of the glass sheet. Compared to glass produced on a float platform, Corning’s proprietary fusion process creates glass with some of the industry’s lowest TTV levels.

By improving TTV, panel makers have the benefit of uniform layer thickness during deposition on the glass substrate and precision patterning in photolithography process. This is especially important from the exposure process perspective, because control of the field of focus is crucial. If the TTV of the glass is outside the field of focus in a moving window range (MWR), a crisp pattern cannot be obtained (Figure 3). Lower glass-substrate TTV therefore provides a significant advantage in the precise photo lithography steps needed for high-resolution displays.

Figure 3



Higher TTV can result in blurred lines that may short-circuit (left image).

ENABLING LARGE GEN SIZES

Screen sizes continue to increase, creating new challenges for panel manufacturers to increase yields, maximize throughput, and reduce material costs. This makes glass utilization increasingly important to panel makers. Therefore, the glass substrate must enable efficient manufacturing and scale up to larger gen sizes (Gen 8.5 and above).

Corning's proprietary fusion process manufactures glass panels at Gen 10.5 sizes (2940 x 3370mm), enabling higher glass utilization for larger-screen sizes. For example, one sheet of Gen 10.5 glass could create eight 65" display panels, or six 75" display panels. This enhanced glass utilization greatly contributes to reduced costs for panel makers and is key for enabling the oxide TFT market.

BALANCING FAST ETCHING AND SLUDGE GENERATION

For oxide TFT to be used in IT or handheld products, one of the key features is a thin and light form factor. To achieve this, the display panel usually needs to be thinned down to roughly 0.15mm / 0.15mm (for the two pieces of glass in the display) using the chemical slimming process. A faster etch rate enables higher throughput and lower costs, but this often comes at the cost of the generation of “sludge.” Sludge can create problems in the etch vendors’ processes and could even cause more cost than the fast etch rate reduced. By using a glass that balances maximizing etch rate with minimized sludge generation, panel makers can optimize their throughput and costs.

SUMMARY

The technology challenges and technical requirements outlined here fuel an industry need for a glass substrate with the right balance of physical properties for oxide TFT technology. For display applications, this includes low total pitch variation, low total thickness variation, and low sag. This package of glass attributes, alongside the ability to scale up manufacturing to large-gen sizes, will help enable the next generation of mid-to-large-size, immersive displays such as 8K TVs.

In the case of high-performance notebooks, tablets, and other handhelds, fast etching and minimal sludge generation become increasingly important glass attributes for better picture quality and response times.

These applications require a shift toward oxide technology, versus the current a-Si and LTPS TFT technologies. As the push for oxide increases, new process and technical challenges emerge for panel makers. To build a display that meets these performance expectations, panel makers require a thermally and dimensionally stable glass to improve yields while achieving the desired resolution.