Flexible Glass Applications & Process Scaling

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Abstract

Substrate choice is critical for overall flexible electronic device and process optimization. Compared to alternatives, glass substrates offer advantages of dimensional and thermal stability, hermeticity, transparency, and surface quality. This paper discusses flexible glass properties that enable high-performance devices using roll-to-roll (R2R) processes. With a specific focus on mechanical reliability, use of glass web has been demonstrated in key R2R building block processes such as: vacuum deposition, lamination, laser patterning, printing, photolithography, and solution coating. Examples of scaled-up glass web processing are described that demonstrate capability for manufacturing widths, lengths, and conveyance speeds.

Introduction

Recently there has been an increasing interest in flexible electronics such as displays,[1,2,3] lighting,[4] photovoltaics,[5,6] and antennas.[7] These applications, in general, value high-performance, light weight, ultra-thin, and conformal devices. The capabilities and advantages of web processing offer the ability to fabricate high quality devices with high throughput manufacturing methods. Specifically, advances in R2R printing, vacuum deposition, and patterning methods enable a next generation of high-resolution, high-performance electronics.

The device substrate is an integral component in the overall optimization of flexible electronics. It affects the final form factor of the device as well as performance and is also critical in determining process parameters and manufacturing yield. The substrate is a significant element in all aspects of the device (design, manufacturing, and performance). This paper describes R2R processes based on Corning® Willow® Glass web that enable high throughput manufacturing of next generation flexible electronic components. Specific examples are described that highlight scaled up R2R processes utilizing glass web manufacturing widths, lengths, and conveyance speeds.

Flexible Glass Advantages

Ultra-slim flexible glass delivers several advantages for device performance and lifetime.[8,9] Besides extrinsic properties related to thickness and weight, flexible glass has several properties that improve device quality and lifetime. These include material benefits in optical quality, surface quality, thermal capability, dimensional stability, chemical compatibility, and hermeticity. Figure 1, for example, shows the optical transmission of glass for 4 different thicknesses. As shown, the transmission in the visible range is limited by the 4% surface reflection loss, and the thickness dependent transmission cut-off in the UV is due to absorption. No significant scattering or haze is present in the flexible glass substrates.

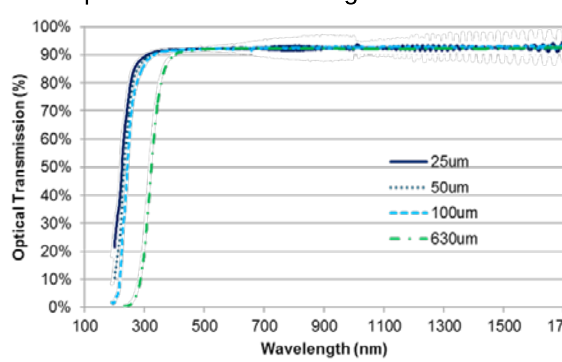

Figure 1: Optical transmission of glass.

As another example, Figure 2 compares the Young's Modulus and hardness of Willow Glass to typical polymer films and stainless steel foil. The higher modulus of the flexible glass contributes to its dimensional stability in device manufacturing processes.

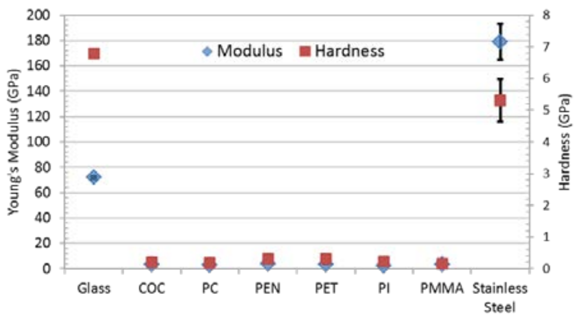

Figure 2: Flexible substrate modulus and hardness.

Flexible Glass Web Mechanical Reliability

As mentioned, flexible glass has several advantages compared to alternative substrates for high-quality device design, performance, and fabrication. However, to be practical for R2R manufacturing, manufacturers must achieve mechanical reliability of flexible glass in web processes. In general, reliability of glass is statistical and related to the distribution of stresses and defects.[10] Mechanical failure occurs when the combination of stress and defect size reach a critical combination. This paper focuses specifically on the reliability of flexible glass for web processing and methods to minimize both handling stresses and defects due to contact damage.

To minimize stresses during handling, large flexible glass substrates should be conveyed with roller systems similar to other flexible web materials. Handling large areas of flexible glass with methods designed for rigid sheet substrates will lead to stress concentrations and mechanical failure. Since the flexural rigidity is proportional to $(\text{thickness})^3$, glass substrates become very flexible as their thickness decreases. To put this in perspective, Figure 3 plots the relative stiffness of a representative glass, stainless steel (SS304), and polymer (PEN and PI) material. This shows that a ≤100µm glass substrate has similar rigidity as other materials typically used in R2R processing. Therefore, flexible glass should be handled in roller conveyance systems appropriately designed for this web material.

In terms of stress associated with roller systems, Figure 4 plots the calculated bend stress of glass as a function of radius for different thicknesses. As shown, a substrate with a thickness of 500µm, typical thickness of rigid LCD substrate applications, experiences a significant bend stress at radii typical of web processing. To reduce bend stress in R2R manufacturing, a glass thickness approaching 100µm or below is targeted. Specific equipment design areas should also be optimized for glass web conveyance such as the web path, roller diameter, steering methods, and tension control.

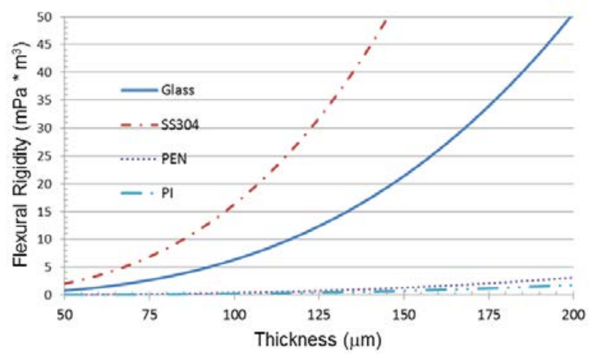

Figure 3: Relative stiffness of flexible glass.

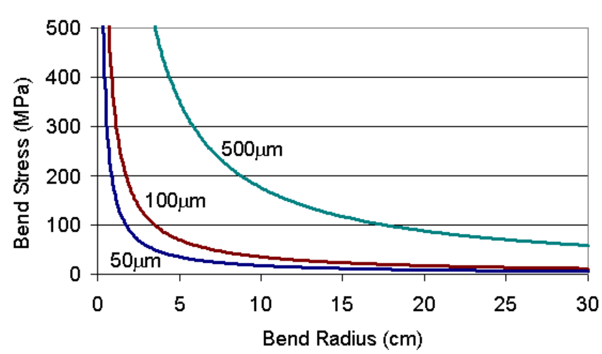

Figure 4: Calculated glass bend stress.

Minimizing defects in the glass caused by contact damage is critical for mechanical reliability. Depending on the defect size and geometry, the failure stress of glass can decrease by >10x as damage occurs. Different options exist for protecting the glass web from contact damage during R2R processing including use of laminates, interleaf, and full or partial coatings.

Computer modeling and simulation significantly contributes to the overall optimization of both the device designs and R2R manufacturing process. As an example, thermo-mechanical modeling has been used to predict glass web shape, stresses, and thermal response within R2R processes. This has then led to identification of targeted parameter windows.

Flexible Glass Web R2R Processing

The central element in glass web R2R processing is conveyance. Once mechanically reliable methods of conveying glass have been demonstrated, a variety of different process modules can be integrated. For example, capabilities for R2R glass web lamination, laser patterning, printing, vacuum deposition, solution coating, and photolithography have previously been discussed. In terms of glass web conveyance, demonstrations highlighting different process scaled-up aspects of width, length, and conveyance speeds have been made. As an example, Figure 5 shows a R2R microreplication process using a 750mm-width and 40m-length glass web substrate.

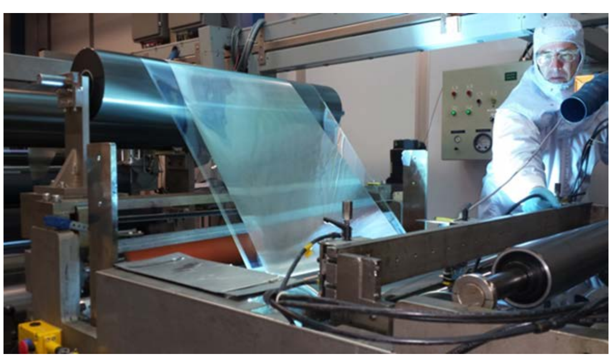

Figure 5: R2R microreplication on glass web.

Conclusion

Flexible glass, ≤200μm thick, offers several advantages for web manufacturing of electronic devices. Benefits of glass include: high quality surface, high optical transmission, thermal and dimensional stability, hermeticity to oxygen and moisture, and chemical compatibility during device fabrication. Similar to other web materials, flexible glass is appropriately conveyed through fabrication equipment using roller systems. Scaled up R2R processes have been demonstrated on manufacturing widths, lengths, and conveyance speeds for glass web. A disruptive ecosystem for flexile glass manufacturing is emerging with new equipment sets being specifically optimized for glass R2R processing.

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