etc., for both organic light emitting diodes (OLED) and liquid crystal displays (LCD), such as may be used in high performance, portable devices (e.g., smart phones, tablets, and notebook computers). Corning® Willow® Glass may also be used for producing electronic components, such as touch sensors, seals for OLED displays and other moisture and oxygen sensitive technologies. Corning® Willow® Glass may be on the order of about 100 μm (micrometers or microns) to 200 μm thick, and highly flexible, having glass characteristics including: a density of about 2.3 – 2.5 g/cc, Young's Modulus of about 70 – 80 GPa, Poisson Ratio of about 0.20 – 0.25, and minimum bend radius of about 185 – 370 mm.

[0010] If respective substrates of Corning® Willow® Glass were processed using typical sheet manufacturing techniques, the thinness and flexibility of the material would likely result in degradation of the material characteristics of the glass, critical failure of the glass, and/or interruption or damage to the sheet processing equipment.

[0011] Embodiments of the present disclosure seek to address the problems of processing flexible substrates, such as thin and flexible glass substrates, in existing sheet manufacturing systems (which are designed for thicker, stiffer substrates). In particular, the methods and apparatus seek to provide for temporarily bonding the flexible substrate to a thicker and/or stiffer carrier substrate, which presents the flexible substrate as having stiffer mechanical characteristics while being processed in the sheet processing system. After processing, the temporary bond is released and the flexible substrate is subject to further manufacturing, processing, or delivery to a customer.

[0011a] In an aspect of the present invention, there is provided a method comprising:

providing a carrier substrate formed from a sheet of material, the carrier substrate having a length dimension in an X-axis, a width dimension in a Y-axis, and a thickness dimension in a Z-axis, where the X-axis and Y-axis define an X-Y plane;

providing a flexible substrate formed from a sheet of material, the flexible substrate having a length dimension in the X-axis, a width dimension in the Y-axis, and a thickness dimension in the Z-axis, and wherein at least one of: (i) the flexible substrate has a thickness of from about 50 μm to about 300 μm, and (ii) the flexible substrate has at least one of: a density of about 2.3 – 2.5 g/cc, a Young's Modulus of about 70 – 80 GPa; a Poisson Ratio of about 0.20 – 0.25, and a minimum bend radius of about 185 – 370 mm;

at least one of stressing and straining the carrier substrate to induce a curvature out of the X-Y plane in a first direction along the Z-axis;

locating the flexible substrate over the carrier substrate, while maintaining the at least one of stressing and straining of the carrier substrate; and

inducing a bond between the flexible substrate and the carrier substrate, wherein the bond initiates at a start area and, thereafter, a bond front propagates the bond from the start area until the flexible substrate is bonded to the carrier substrate,

wherein the induced curvature out of the X-Y plane in the first direction along the Z-axis in the carrier substrate is maintained prior to, and at least partially during, the bonding process such that characteristics of the bond front tend to cause the bonded flexible substrate and the carrier substrate to curve out of the X-Y plane in a second direction along the Z-axis, opposite to the first direction.

[0011b] There is also disclosed an apparatus comprising:

a carrier substrate formed from a sheet of material, the carrier substrate having a length dimension in an X-axis, a width dimension in a Y-axis, and a thickness dimension in a Z-axis, where the X-axis and Y-axis define an X-Y plane; and

a flexible substrate formed from a sheet of material, which is bonded to the carrier substrate, the flexible substrate having a length dimension in the X-axis, a width dimension in the Y-axis, and a thickness dimension in the Z-axis, wherein at least one of: (i) a flexibility of the flexible substrate is substantially more flexible than a flexibility of the carrier substrate, and (ii) the thickness of the flexible substrate is substantially less than a thickness of the carrier substrate,

wherein an amount of deformation out of the X-Y plane after bonding is less than at least one of: (i) about 200 um; (ii) about 100 um; (iii) about 75 um; and (iii) about 50 um.

[0012] Other aspects, features, and advantages will be apparent to one skilled in the art from the description herein taken in conjunction with the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

[0013] For the purposes of illustration, there are forms shown in the drawings that are presently preferred, it being understood, however, that the embodiments disclosed and described herein are not limited to the precise arrangements and instrumentalities shown.

[0014] FIG. 1 is a perspective view, schematic illustration of a process in which a flexible substrate is bonded to a carrier substrate in preparation for processing the flexible substrate in a conventional sheet manufacturing system;

CLAIMS:

1. A method comprising:

providing a carrier substrate formed from a sheet of material, the carrier substrate having a length dimension in an X-axis, a width dimension in a Y-axis, and a thickness dimension in a Z-axis, where the X-axis and Y-axis define an X-Y plane;

providing a flexible substrate formed from a sheet of material, the flexible substrate having a length dimension in the X-axis, a width dimension in the Y-axis, and a thickness dimension in the Z-axis, and wherein at least one of: (i) the flexible substrate has a thickness of from about 50 μm to about 300 μm, and (ii) the flexible substrate has at least one of: a density of about 2.3 – 2.5 g/cc, a Young's Modulus of about 70 – 80 GPa; a Poisson Ratio of about 0.20 – 0.25, and a minimum bend radius of about 185 – 370 mm;

at least one of stressing and straining the carrier substrate to induce a curvature out of the X-Y plane in a first direction along the Z-axis;

locating the flexible substrate over the carrier substrate, while maintaining the at least one of stressing and straining of the carrier substrate; and

inducing a bond between the flexible substrate and the carrier substrate, wherein the bond initiates at a start area and, thereafter, a bond front propagates the bond from the start area until the flexible substrate is bonded to the carrier substrate,

wherein the induced curvature out of the X-Y plane in the first direction along the Z-axis in the carrier substrate is maintained prior to, and at least partially during, the bonding process such that characteristics of the bond front tend to cause the bonded flexible substrate and the carrier substrate to curve out of the X-Y plane in a second direction along the Z-axis, opposite to the first direction.

2. The method of claim 1, wherein the at least one of stressing and straining includes mechanically bending the carrier substrate cylindrically.

3. The method of claim 2, wherein:

the at least one of stressing and straining includes mechanically bending the carrier substrate about an axis that is spaced away from the X-Y plane in the Z-axis direction, and that is parallel to the Y-axis, to induce the curvature;

the curvature is characterized by a curvature radius from the axis to the carrier substrate such that the curvature out of the X-Y plane is in the first direction along the Z-axis;

the start area extends substantially linearly along a line parallel to the Y-axis;

the bond front extends substantially linearly along a line parallel to the Y-axis; and

the bond front propagates away from the start area and in a direction transverse to the Y-axis.

4. The method of claim 3, wherein the start area is induced by pressing the flexible substrate toward, and into contact with, the carrier substrate along a linearly extending zone, and further wherein the linear extending zone is achieved by pressing against the flexible substrate via at least one of: (i) a leaf-spring deflection element; (ii) a rocker press; (iii) a multi-point linear press; (iv) one or more air jets; (v) one or more air bearings; and (vi) one or more ultrasonic bearings.

5. The method of claim 1, wherein the at least one of stressing and straining includes mechanically bending the carrier substrate into a dome shape.

6. The method of claim 5, wherein:
the at least one of stressing and straining includes heating at least one of the flexible substrate and the carrier substrate to differing temperatures prior to and during the inducement of the bond and propagation of the bond front; and
permitting the flexible substrate and the carrier substrate to reach thermal equilibrium after the bond is achieved.

7. The method of claim 6, wherein:
the start area is substantially a circular area or central point; and the bond front extends substantially radially outwardly from the start area.

8. The method of any one of claims 1 to 7, wherein the flexible substrate exhibits at least one of: (i) a flexibility that is more flexible than a flexibility of the carrier substrate, and (ii) a thickness that is less than a thickness of the carrier substrate.