

METHODS OF PROCESSING INCLUDING PEELING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 62/081,892 filed on November 19, 2014, the content of which is relied upon and incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates generally to methods of processing including peeling and, more particularly, to methods of processing including the step of peeling a leading peripheral edge of a first substrate from a second substrate wherein at least one of the substrates may comprise a glass substrate and/or a silicon wafer.

BACKGROUND

[0003] There is interest in using thin, flexible glass in the fabrication of flexible electronics or other devices. Flexible glass can have several beneficial properties related to either the fabrication or performance of electronic devices, for example, liquid crystal displays (LCDs), electrophoretic displays (EPD), organic light emitting diode displays (OLEDs), plasma display panels (PDPs), touch sensors, photovoltaics, etc. One component in the use of flexible glass is the ability to handle the glass in a sheet format and not in a roll format.

[0004] To enable the handling of flexible glass during processing of the flexible glass, the flexible glass is typically bonded to a relatively rigid carrier substrate using a polymer binding agent. Once bonded to the carrier substrate, the relatively rigid characteristics and size of the carrier substrate allow the bonded structure to be handled in production without undesired bending or causing damage to the flexible glass. For example, thin-film transistor (TFT) components may be attached to the flexible glass in the production of LCDs.

[0005] After processing, the flexible glass is removed from the carrier substrate. However, given the delicate nature of the flexible glass, the force applied to detach the flexible glass from the carrier substrate can damage the flexible glass. Moreover, the separation process, which typically includes the insertion of an implement to the flexible glass-carrier interface, can often damage the carrier substrate as well, rendering the carrier substrate unusable for future use. Accordingly, there is a need for practical solutions for detaching thin, flexible glass from a carrier substrate, that reduce the potential for damaging the flexible glass and/or carrier substrate.

SUMMARY

[0006] The following presents a simplified summary of the disclosure in order to provide a basic understanding of some example aspects described in the detailed description.

[0007] In an aspect of the disclosure, a method is provided for processing a first substrate with a first major surface of the first substrate removably bonded to a first major surface of a second substrate. The method comprises the step (I) of bonding a flexible membrane to a second major surface of the first substrate, wherein the flexible membrane includes a tab that extends off a leading peripheral edge of the first substrate. The method further includes the step (II) of peeling the leading peripheral edge of the first substrate from the second substrate by applying a force to the tab.

[0008] In one example of the aspect, the first substrate comprises a substrate selected from the group consisting of: a glass substrate and a silicon wafer.

[0009] In another example of the aspect, the first substrate includes a thickness of from about 100 microns to about 300 microns.

[0010] In still another example of the aspect, the second substrate comprises a carrier substrate including a thickness of from about 300 microns to about 700 microns.

[0011] In yet another example of the aspect, the second substrate comprises a carrier substrate including a footprint that is larger than a footprint of the first substrate.

[0012] In a further example of the aspect, prior to step (II), the method further comprises the step of processing the first substrate while the first substrate is bonded to the second substrate. In one particular example, the step of processing the first substrate occurs prior to step (I).

[0013] In still a further example of the aspect, the leading peripheral edge includes a length defined between a first lateral edge and a second lateral edge of the first substrate, and step (I) includes bonding the flexible membrane to the second major surface of the first substrate such that the flexible membrane extends along substantially the entire length of the leading peripheral edge. In one particular example, step (II) uniformly applies the force to the tab along the length of the leading peripheral edge. In another particular example, step (II) peels the leading peripheral edge of the first substrate from the second substrate substantially simultaneously along the entire length of the leading peripheral edge.

[0014] In yet another example of the aspect, after step (II), further comprising the step of completely removing the first substrate from the second substrate. In one particular example,

the step of completely removing the first substrate from the second substrate comprises completely peeling the first substrate from the second substrate.

[0015] In another example of the aspect, the method can also optionally include the steps of preselecting a minimum bend radius of the first substrate and selecting a flexible membrane to increase the effective stiffness of the first substrate to maintain a bend radius of the first substrate above the minimum bend radius while peeling the first substrate from the second substrate.

[0016] In still another example of the aspect, the method further comprises the step of controlling a bend radius of the first substrate while peeling the first substrate from the second substrate.

[0017] In yet another example of the aspect, step (I) bonds the flexible membrane to cover substantially the entire second major surface of the first substrate.

[0018] In a further example of the aspect, step (I) bonds the flexible membrane to the second major surface of the first substrate such that the tab extends a distance of from about 5 cm to about 20 cm off the leading peripheral edge of the first substrate.

[0019] In yet a further example of the aspect, after step (II), the method further comprises the step of removing the flexible membrane from the first substrate. In one particular example, the step of removing the flexible membrane from the first substrate includes exposing the flexible membrane to ultraviolet light to release the flexible membrane from the second major surface of the first substrate.

[0020] In still a further example of the aspect, step (II) includes vacuum attaching the tab to a vacuum attachment member and then applying the force to the tab with the vacuum attachment member.

[0021] In another example of the aspect, the method further comprises the step of determining a bond strength between the leading peripheral edge of the first substrate and the second substrate based on information obtained during step (II).

[0022] The aspect may be carried out alone or with one or any combination of the examples of the aspect discussed above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] These and other aspects are better understood when the following detailed description is read with reference to the accompanying drawings, in which:

[0024] **FIG. 1** is a schematic side view of an example peeling apparatus;

- [0025] FIG. 2 is a front view of the peeling apparatus along line 2-2 of FIG. 1;
- [0026] FIG. 3 is a top view of a vacuum plate of the peeling apparatus along line 3-3 of FIG. 2;
- [0027] FIG. 4 is a bottom view of a vacuum attachment member and an arm of the peeling apparatus along line 4-4 of FIG. 2;
- [0028] FIG. 5 is a schematic side view of the peeling apparatus of FIG. 1 in an open orientation;
- [0029] FIG. 6 is a schematic side view of the peeling apparatus of FIG. 1 in an open orientation with a carrier substrate vacuum attached to the vacuum plate;
- [0030] FIG. 7 is a schematic side view of the peeling apparatus of FIG. 1 in a closed orientation with the carrier substrate vacuum attached to the vacuum plate and the attachment member vacuum attached to a tab extending off a leading peripheral edge of a first substrate;
- [0031] FIG. 8 schematically illustrates a force being uniformly applied to the tab along a length of the leading peripheral edge;
- [0032] FIG. 9 is an enlarged partial cross section of the peeling apparatus along line 9-9 of FIG. 8;
- [0033] FIG. 10 is a partial view of FIG. 9 illustrating the step of peeling the leading peripheral edge of the first substrate from the carrier substrate by applying a force to the tab;
- [0034] FIG. 11 illustrates a step of controlling a bend radius of the first substrate while peeling the first substrate from the carrier substrate;
- [0035] FIG. 12 illustrates the first substrate being completely peeled from the carrier substrate;
- [0036] FIG. 13 is a schematic side view of the peeling apparatus of FIG. 1 in an open orientation with a first substrate vacuum attached to the vacuum plate;
- [0037] FIG. 14 is a schematic side view of the peeling apparatus of FIG. 1 in a closed orientation with the first substrate vacuum attached to the vacuum plate and the attachment member vacuum attached to a tab extending off a leading peripheral edge of a carrier substrate;
- [0038] FIG. 15 illustrates a step of controlling a bend radius of the carrier substrate while peeling the carrier substrate from the first substrate;
- [0039] FIG. 16 is a schematic side view of the peeling apparatus of FIG. 1 in an open orientation with a second carrier substrate vacuum attached to the vacuum plate;

[0040] FIG. 17 is a schematic side view of the peeling apparatus of FIG. 1 in a closed orientation with the second carrier substrate vacuum attached to the vacuum plate and the attachment member vacuum attached to a tab extending off a leading peripheral edge of a first carrier substrate;

[0041] FIG. 18 illustrates a step of controlling a bend radius of the first carrier substrate while peeling the first carrier substrate from an intermediate substrate and the second carrier substrate; and

[0042] FIG. 19 illustrates example steps in methods of processing a first substrate with a first major surface of the first substrate removably bonded to a first major surface of a second substrate.

DETAILED DESCRIPTION

[0043] Examples will now be described more fully hereinafter with reference to the accompanying drawings in which example embodiments are shown. Whenever possible, the same reference numerals are used throughout the drawings to refer to the same or like parts. However, aspects may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein.

[0044] Peeling apparatus of the disclosure can be used to facilitate removal of a first substrate bonded to a second substrate. In one example, the peeling apparatus can facilitate initial or complete separation of a silicon wafer or a glass substrate from a carrier substrate. For instance, the peeling apparatus can be useful in initially or completely peeling a glass substrate from a carrier substrate although the carrier substrate can be initially or completely peeled from the glass substrate and/or another carrier substrate in further examples.

[0045] Flexible glass sheets are often used to manufacture liquid crystal displays (LCDs), electrophoretic displays (EPD), organic light emitting diode displays (OLEDs), plasma display panels (PDPs), touch sensors, photovoltaics, etc. To enable the handling of flexible glass sheet during processing, the flexible glass sheet may be bonded to a rigid carrier substrate using a binding agent, for example a polymer binding agent. The carrier substrate may be fabricated from glass, resin or other materials capable of withstanding conditions during processing of the substrate (e.g., glass substrate, silicon wafer, etc.) removably bonded to the carrier substrate. In some examples, the carrier substrate and the substrate bonded to the carrier substrate can each include a thickness defined between the respective major surfaces of the substrates. The carrier substrate can optionally introduce a desired level of

rigidity by providing the carrier substrate with a thickness that is greater than the thickness of the substrate removably bonded to the carrier substrate. Furthermore, in some examples, the carrier substrate can be selected with a thickness wherein the overall thickness of the carrier substrate and the substrate bonded to the carrier substrate is within a range that can be used with existing processing machinery configured to process relatively thick glass substrates having a thickness within the range of the overall thickness of the carrier substrate and the substrate bonded to the carrier substrate.

[0046] In some examples, the first substrate can comprise a glass substrate or a silicon wafer with a thickness of from about 100 microns to about 300 microns. In further examples, the carrier substrate can include a thickness of from about 300 microns to about 700 microns. In such examples, the carrier substrate may include a thickness that is greater than the thickness of the substrate (e.g., glass substrate or silicon wafer) bonded to the carrier substrate.

[0047] The rigid characteristics and size of the carrier substrate allow the bonded glass sheet to be handled in production without significant bending that may otherwise cause damage to the flexible glass sheet and/or components mounted to the flexible glass sheet. After processing (e.g., handling, adding components, treating, etc.), a peeling apparatus of the disclosure may be used to initially or completely peel the carrier substrate from the bonded substrate (e.g., glass substrate or silicon wafer) or the bonded substrate(s) from the carrier substrate.

[0048] Turning to **FIGS. 1 & 2**, there is shown an example peeling apparatus **101** configured to peel a first substrate from a second substrate. Throughout the disclosure, the first substrate can comprise a silicon wafer, glass substrate (e.g., a thin, flexible glass substrate), or other substrate removably bonded to a second substrate such as a carrier substrate. In further examples, the second substrate can comprise the silicon wafer, glass substrate, or other substrate removably bonded to the first substrate comprising the carrier substrate.

[0049] The peeling apparatus **101** further includes a vacuum plate **103** configured to releasably secure one of the substrates in place. For example, the vacuum plate can be vacuum attached to a major surface of the second substrate to releasably secure the second substrate in place. The vacuum plate **103** includes a length “**L1**” (see **FIG. 1**) and a width “**W1**” (see **FIG. 2**). In the illustrated example, the length “**L1**” is greater than the width “**W1**” although the length and width may be substantially equal or the width may be greater than the length in further examples.

[0050] As shown in **FIG. 3**, the vacuum plate **103** can include one or more vacuum ports, such as the illustrated plurality of vacuum ports **301** open at a surface **303** (e.g., a substantially planar surface). The plurality of vacuum ports **301** may be in fluid communication with a vacuum source **104** such as vacuum tank, vacuum pump, etc. As shown in **FIGS. 1 and 9**, a vacuum conduit **901**, such as a flexible hose, may provide fluid communication between the plurality of vacuum ports **301** and the vacuum source **104**. In one example, as shown in **FIG. 9**, a vacuum chamber **903** may be placed in fluid communication with the plurality of vacuum ports **301** such that the plurality of vacuum ports **301** are in fluid communication with the vacuum conduit **901**.

[0051] Although not shown, one or more standoffs may be provided to prevent actual engagement between the major surface of the substrate and the surface **303** of the vacuum plate **103**. Such standoffs may comprise a peripheral standoff, such as a ring circumscribing the plurality of vacuum ports **301**. In addition or alternatively, the standoffs can comprise pillars distributed between vacuum ports throughout the pattern of vacuum ports **301**. The pillars can comprise various materials such as a polymeric material. The standoffs can extend a distance of about 1.6 mm (e.g., 1/16 of an inch) although other distances may be used in further examples.

[0052] Referring to **FIG. 1**, the vacuum plate **103** can optionally be configured to translate along a translation axis **105** in one of a first direction **107a** and a second direction **107b** opposite the first direction. For instance, as schematically illustrated, a plurality of bearings **109** may receive a translation rail **111** extending along the translation axis **105**. In some examples, the vacuum plate **103** may freely translate in one of the directions **107a, 107b** as the bearings glide along the translation rail **111**. Optionally, a locking member, such as the illustrated set screw **113**, may selectively lock the vacuum plate **103** relative to the translation rail **111**. In a locked orientation, the vacuum plate **103** may be prevented from moving relative to the translation rail **111**. Alternatively, in the unlocked orientation, the vacuum plate **103** may be able to translate relative to the translation rail **111** along one of the directions **107a, 107b**. The vacuum plate **103** may be selectively locked or unlocked to accommodate different peeling procedures. In applications where only locked orientations are contemplated, the translation mechanism may be discarded altogether. In such examples, the vacuum plate **103** may be fixedly mounted relative to a support surface **115** such as a floor, table top, stand or other support surface.

[0053] The peeling apparatus **101** further includes a vacuum attachment member **117** configured to be releasably vacuum attached relative to a leading peripheral edge of the first substrate. In order to facilitate the vacuum attachment, the vacuum attachment member can include one or more vacuum ports. For instance, as shown in **FIG. 4**, the one or more vacuum ports can comprise a plurality of vacuum ports **401** open at a surface **403** (e.g., a substantially planar surface) of the vacuum attachment member **117**. In one example, the plurality of vacuum ports **401** may be arranged in a pattern to distribute force along a width “**W2**” of the vacuum attachment member **117**.

[0054] The plurality of vacuum ports **401** may be in fluid communication with a vacuum source **118** such as vacuum tank, vacuum pump, etc. As shown in **FIGS. 1 and 9**, a vacuum conduit **905**, such as a flexible hose, may provide fluid communication between the plurality of vacuum ports **401** and the vacuum source **118**. In one example, as shown in **FIG. 9**, a vacuum chamber **907** may be placed in fluid communication with the plurality of vacuum ports **401** such that the plurality of vacuum ports **401** are in fluid communication with the vacuum conduit **905**.

[0055] The vacuum attachment member **117** may further include a standoff that, in some examples, may prevent actual engagement between the vacuum attachment member **117** and a substrate surface. For instance, if the vacuum attachment member **117** is vacuum attached directly to the first substrate (e.g., glass substrate, silicon wafer, carrier substrate), the standoff can act as a bumper to protect the glass surfaces from damage due to direct contact between the vacuum attachment member and the first substrate. As schematically shown in **FIG. 4**, one example standoff, if provided, may comprise a peripheral ring-shaped standoff **405** that circumscribes the plurality of vacuum ports **401**. The standoff **405** can comprise various materials such as a polymeric material and, in some examples, can extend a distance of about 1.6 mm (e.g., 1/16 of an inch) from the surface **403** of the vacuum attachment member **117**.

[0056] Referring to **FIGS. 1 and 4**, the peeling apparatus **101** further includes an arm **119** supporting the vacuum attachment member **117**. As shown, the arm **119** can comprise a plate although the arm may comprise a frame, beam, or other structure configured to support the vacuum attachment member **117**. In some examples, the arm **119** can further include a length “**L2**” that is greater than the length “**L1**” of the vacuum plate **103**. Providing the arm **119** with the relatively longer length “**L2**” can allow the vacuum attachment member **117** to be

spaced laterally away from the surface **303** of the vacuum plate **103** and beyond a leading edge **121** of the vacuum plate. Spacing the vacuum attachment member **117** laterally away from the surface **303** of the vacuum plate **103** can allow the vacuum attachment member **117** to be vacuum attached to a tab without the tab being vacuum attached to the surface **303** of the vacuum plate **103**.

[0057] Although not shown, in alternative examples the arm **119** may have a length “**L2**” that is equal to or less than the length “**L1**” of the vacuum plate **103**. Such a configuration can allow the vacuum attachment member **117** to be vacuum attached directly to a major surface of the first substrate while the second substrate is vacuum attached to the vacuum plate **103**.

[0058] The arm **119** is also pivotally attached relative to the vacuum plate **103**. For example, as shown in **FIG. 1**, the trailing end **123** of the vacuum plate **103** can be pivotally attached relative to a trailing end **125** of the arm **119** with a hinge. In some example, the hinge can comprise a float hinge **127** although fixed hinge configurations may be used in alternative examples. The float hinge **127** can include a hinge pin **129** configured to translate and rotate within the slot **131**. Consequently, the float hinge **127** can allow different thickness substrate stacks to be processed with the peeling apparatus **101**.

[0059] As shown in **FIG. 1**, the peeling apparatus **101** can also include an actuator **133** configured to apply a force “**F**” to the vacuum attachment member **117** to lift the vacuum attachment member **117** and consequently cause the arm **119** to pivot in direction **135** about the float hinge **127**. In just one example, the force “**F**” can be applied through a link **137** connected (e.g., with hook **138**) to a flexible filament **139** (e.g., wire, cable, etc). For instance, as shown in **FIG. 2**, one end **139a** of the filament **139** can be attached to a first pin **201a** extending from a first side of the vacuum attachment member **117** while the other end **139b** of the filament **139** can be attached to a second pin **201b** extending from a second side of the vacuum attachment member **117**. Application of the force “**F**” through the link **137** can result in application of tensile forces “**F1**”, “**F2**” to the first pin **201a** and second pin **201b**. Moreover, as shown in **FIG. 1**, the moment arm about the float hinge **127** is maximized since the pins **201a**, **201b** are positioned at the outermost leading end of the vacuum attachment member **117**. As such the leverage may be maximized to more efficiently apply the force “**F**” to initiate peeling of the substrates.

[0060] As further illustrated in **FIGS. 1 and 2**, the peeling apparatus **101** may also include a load sensor **141** configured to sense the force “**F**” being applied by the actuator **133**.

Information from the load sensor **141** may be sent back to a control device **143** (e.g., programmable logic controller) by way of communication line **141a**. The control device **143** can be configured to (e.g., “programmed to”, “encoded to”, designed to”, and/or “made to”) control the actuator **133** by way of communication line **133a** and the vacuum sources **104**, **118** by way of respective communication lines **104a**, **118a**.

[0061] Methods of processing will now be described with initial reference to **FIG. 19**. The method can start with step **1901** with a first substrate including a first major surface of the first substrate removably bonded to a first major surface of a second substrate. Throughout the application, the first substrate can be removably bonded to the second substrate by a polymer binding agent or other material that can withstand processing conditions while permitting the substrates to be subsequently peeled at least partially apart.

[0062] In one example of step **1901**, as shown in **FIGS. 6-12**, the method can start with a first substrate **601** comprising a glass substrate (e.g., a thin, flexible glass substrate) or a silicon wafer and a second substrate **603** comprising a carrier substrate (e.g., glass carrier substrate). As shown in **FIG. 9**, in some examples, the first substrate **601** can include a thickness **T1** from about 100 microns to about 300 microns between a first major surface **601a** and a second major surface **601b** of the first substrate **601**. As further shown in **FIG. 9**, in some examples, the second substrate **603** can include a thickness **T2** from about 300 microns to about 700 microns between a first major surface **603a** and a second major surface **603b** of the second substrate **603**. As further illustrated in **FIG. 9**, in some examples, the thickness **T2** of the second substrate **603** (e.g., carrier substrate) can be greater than the thickness **T1** of the first substrate **601**. Providing a relatively thicker carrier substrate can help increase the effective stiffness of the first substrate (e.g., glass substrate or silicon wafer) to facilitate processing of the first substrate. A relatively thicker carrier substrate can also help significantly contribute to increasing the effective stiffness of the first substrate bonded to the second substrate.

[0063] As illustrated in **FIG. 9**, the first major surface **601a** of the first substrate **601** can be removably bonded to the first major surface **603a** of the second substrate **603**. Moreover, as further shown in **FIG. 9** the second substrate **603** can include a footprint that is larger than a footprint of the first substrate **601**. Indeed, the leading peripheral edge **909** of the second substrate **603** extends beyond a leading peripheral edge **911** of the first substrate **601**. In addition, the trailing peripheral edge **913** of the second substrate **603** can extend beyond a

trailing peripheral edge **915** of the first substrate **601**. In fact, in some examples, all of the peripheral edges of the second substrate **603** can optionally extend beyond the corresponding peripheral edges of the first substrate **601** by various distances, for example from about 0.5 mm to about 3 mm. Providing the second substrate **603** with a larger footprint than the first substrate **601** can help protect the relatively fragile peripheral edges of the first substrate from damage during processing. Indeed, any impact to the edges of the bonded substrates would tend to occur at the outwardly extending peripheral edges of the second substrate **603** that would act to protect the relatively fragile outer peripheral edges of the first substrate **601**.

[0064] Although not shown in **FIGS. 6-12**, the footprint of the first substrate **601** and the second substrate **603** may be substantially equal in further examples. Providing substantially equal footprints may simplify manufacturing. For example, the first and second substrates may be first bonded together and then they may be separated along a common separation path wherein the substrates consequently have substantially identical footprints.

[0065] In still another example, although not shown in **FIGS. 6-12**, the first substrate may have a footprint that is larger than the second substrate such that one or all of the outer peripheral edges of the first substrate extend beyond the second substrate. Alternatively, regardless of the relative footprint size, although not shown, the leading peripheral edge **911** of the first substrate can optionally include an overhung portion (e.g., tab) that extends beyond the leading peripheral edge **909** of the second substrate, for example, from about 50 microns to about 150 microns such as about 100 microns. Such examples can be beneficial to help peel the leading peripheral edge of the first substrate from the second substrate.

[0066] As further shown in **FIG. 19**, any of the methods of the disclosure can optionally proceed along arrow **1903** to a step **1905** of processing the first substrate **601** while the first substrate **601** is bonded to the second substrate **603**. The first substrate **601** can be processed, for example, to include electronics, color filters, touch sensors, liquid crystal wells and other electronics in display applications. In another example, processing can include etching of the glass or otherwise working the glass substrate. When using a silicon wafer, processing can include cutting the silicon wafer into smaller pieces or otherwise processing the silicon wafer to manufacture electronic components.

[0067] As shown by arrow **1907** in **FIG. 19**, after the step **1905** of processing, the method can optionally proceed to the step **1909** of bonding a flexible membrane to a second major surface of the first substrate, wherein the flexible membrane includes a tab that extends off a

leading peripheral edge of the first substrate. For example, as shown in **FIGS. 9 and 10**, a flexible membrane **917** is bonded to the second major surface **601b** of the first substrate **601**. The flexible membrane **917** can have a wide range of thicknesses, for example, from about 75 microns to about 150 microns although other thicknesses may be provided in further examples. The flexible membrane can be fabricated from a resin (e.g., clear resin), such as a polymeric material. In one example, the flexible membrane can be fabricated from a polyimide material configured to resist high temperature and configured to transit a relatively high force in tension. In particular examples, the flexible membrane can be fabricated from PVC, polyolefin, polyethylene or other materials.

[0068] The flexible membrane can also include a pressure sensitive adhesive that can provide significant strength to promote a peeling process of the first substrate from the second substrate while also allowing for subsequent removal without leaving residual material on the first substrate. In one example, the adhesive material can be broken down by exposure to ultraviolet light. A specific example of flexible material with a UV sensitive adhesive material can comprise dicing tape commonly used as a backing tape during silicon wafer dicing.

[0069] As shown in **FIG. 8**, the leading peripheral edge **911** of the first substrate **601** can include a length “**L3**” defined between a first lateral edge **801a** and a second lateral edge **801b** of the first substrate **601**. As shown in the figures, the length “**L3**” extends in the same direction as the width “**W1**” of the vacuum plate **103**. Optionally the step of bonding the flexible membrane **917** can include bonding the flexible membrane to the second major surface **601b** of the first substrate **601** such that the flexible membrane **917** extends along substantially the entire length “**L3**” of the leading peripheral edge **911** of the first substrate **601**. In further examples, the flexible membrane **917** may extend from about 70% to about 100% of the length “**L3**”, such as from about 85% to about 100%, such as from about 90% to about 100%, such as about 95% to about 100% of the length “**L3**”. Increasing the extent to which the flexible membrane **917** extends along the length “**L3**” can help evenly distribute the force across the length “**L3**” of the leading peripheral edge **911** to reduce stress concentrations and allow simultaneous peeling along the entire length “**L3**” of the flexible membrane **917**.

[0070] The step **1909** of bonding the flexible membrane **917** can optionally bond the flexible membrane **917** to cover substantially the entire second major surface **601b** of the first

substrate **601**. Indeed, as shown in **FIG. 9**, the flexible membrane **917** extends the entire length of the first substrate **601** from the leading peripheral edge **911** to the trailing peripheral edge **915** of the first substrate **601**. Bonding the flexible membrane **917** to over substantially the entire second major surface **601b** of the first substrate **601** can help protect the second major surface **601b** from damage and can also help adjust the overall effective stiffness of the first substrate **601**. Although not shown, in further examples, the flexible membrane **917** may be bonded across only a portion of the second major surface **601b**. For example, the flexible membrane **917** may extend a distance at least about 8 cm (e.g., about 3 inches) from the leading peripheral edge **911** in a direction from the leading peripheral edge **911** to the trailing peripheral edge **915** of the first substrate **601**. Extending the flexible membrane **917** over only part of the second major surface **601b** can expose portions of the second major surface **601b** for processing even while the flexible membrane **917** is bonded to a portion of the second major surface **601b** of the first substrate **601**. Extending the flexible membrane **917** over only part of the second major surface **601b** can also reduce material costs and can reduce the time to subsequently remove the flexible membrane **917** from the first substrate **601**. Extending the flexible membrane **917** over only part of the second major surface **601b** may be useful when it is not necessary to stiffen portions of the first substrate **601** that may already have sufficient stiffness for the particular process application.

[0071] As shown in **FIG. 10**, the flexible membrane **917** includes a tab **1001** that extends off the leading peripheral edge **911** of the first substrate **601** by a distance “**D**”. As the lower surface **1003** of the tab **1001** can include a pressure-sensitive adhesive, the end of the tab may be folded under itself to cover the pressure-sensitive adhesive, thereby preventing the tab **1001** from inadvertently bonding to adjacent portions of the second substrate **603** or the peeling apparatus **101**. For instance, in some examples, the flexible membrane may extend about twice the distance “**D**” and then be folded under and adhered to itself to form a folded tab with an effective distance “**D**”. In some examples, the distance “**D**” of the tab **1001** extending off the leading peripheral edge **911** of the first substrate **601** can be within a range of from about 5 cm (2 inches) to about 20 cm (8 inches) although other sized tabs may be provided in further examples. Moreover, the illustrated tab can extend the entire length “**L3**” of the leading peripheral edge **911**.

[0072] As shown by arrow **1907** in **FIG. 19**, the step **1909** of bonding can be carried out after the step **1905** of processing. In further example, as indicated by arrow **1911**, the method can

proceed directly to the step **1909** of bonding. For instance, the method may start at step **1901** with the processing step already carried out. For example, the method may begin with the first substrate bonded to the second substrate wherein the first substrate has been processed while the first substrate was bonded on the second substrate. In such examples, the method can start at step **1901** and proceed directly to the step **1909** of bonding. In another example, as mentioned previously, the step **1905** of processing may be carried out after the step **1909** of bonding as indicated by arrow **1913**. Such an order of steps can proceed, for example, when the flexible membrane **917** does not interfere with the step **1905** of processing.

[0073] As indicated by arrows **1915**, **1917**, the method can eventually proceed to a step **1919** of peeling the leading peripheral edge **911** of the first substrate **601** from the second substrate **603** by applying a force “F” to the tab **1001**. As shown in **FIG. 5**, to prepare for the step **119** of peeling, the arm **119** together with the vacuum attachment member **117** attached to a distal end of the arm can be pivoted in direction **501** about the float hinge **127** to an open orientation.

[0074] Next, as shown in **FIG. 6**, after the second substrate **603** is positioned over the vacuum plate **103**. The vacuum source **104** can apply vacuum and consequent suction through the plurality of vacuum ports **301**. The second major surface **603b** of the second substrate **603** is thereafter vacuum attached to the surface **303** of the vacuum plate **103**. Once vacuum attached, the second substrate **603** has a fixed shape. In the illustrated example, the second substrate **603** can be fixed in a substantially flat planar shape although other shapes may be desired in further examples. Fixing the shape can help secure the second substrate **603** firmly in place to facilitate the peeling process.

[0075] Before, during or after vacuum attaching the second substrate **603** to the vacuum plate **103**, the arm **119** together with the vacuum attachment member **117** can be pivoted in direction **605** about the float hinge **127** to a closed orientation shown in **FIG. 7**. In the closed orientation shown in **FIG. 7**, the arm **119** extends across the first substrate **601** in a direction from the trailing peripheral edge **915** to the leading peripheral edge **911** of the first substrate **601**. As further shown in **FIG. 7**, the hinge pin **129** may travel up the slot **131** of the float hinge **127** in response to the arm being closed over the overall thickness of the first and second substrate.

[0076] As shown in **FIG. 7**, the step **1919** of peeling can include the step of vacuum attaching the tab **1001** to the vacuum attachment member **117**. Indeed, the vacuum source

118 can apply vacuum and consequent suction through the plurality of vacuum ports **401** such that the tab **1001** is vacuum attached to the surface **403** of the vacuum attachment member **117**. The step **1919** of peeling can then apply the force “**F**” to the tab **1001** with the vacuum attachment member **117**. Indeed, with reference to **FIG. 2**, the actuator **133** can apply the force “**F**” in the upward direction that causes tensile forces “**F1**” and “**F2**” to be applied to the pins **201a**, **201b** of the vacuum attachment member **117**.

[**0077**] As shown by the force distribution represented schematically by a row of parallel arrows in **FIG. 8**, the method can uniformly apply the force “**F**” to the tab **1001** along the length “**L3**” of the leading peripheral edge **911** of the first substrate **601**. As such, stress can be distributed evenly across the leading peripheral edge **911** to avoid unnecessarily high stress concentrations along the leading peripheral edge. As shown in **FIG. 10**, since the force is being applied a distance “**D**” from the leading peripheral edge **911**, the force can be concentrated at the interface between the leading peripheral edge **911** and the second substrate **603**. Eventually, the stress at the leading peripheral edge **911** results in an initial separation **1005** between the leading peripheral edge **911** and the second substrate **603**.

Initial separation may begin at one end of the leading peripheral edge. Alternatively, in some examples, the step of peeling can peel the leading peripheral edge **911** of the first substrate **601** from the second substrate **603** substantially simultaneously along the entire length “**L3**” of the leading peripheral edge **911**. Simultaneous peeling along the entire length “**L3**” of the leading peripheral edge **911** can be achieved with uniform application of force along the entire length of the leading peripheral edge and can help reduce unnecessary stress spikes along the length that may otherwise damage the first substrate.

[**0078**] Sometime after the step **1919** of peeling the leading peripheral edge **911** of the first substrate **601**, the method can optionally include the step **1921** of determining a bond strength between the leading peripheral edge **911** of the first substrate **601** and the second substrate **603** based on information obtained during the step **1919** of peeling. For instance, information (e.g., a force measurement) from the load sensor **141** can be transmitted by the communication line **141a** to the control device **143**. The control device **143** can be configured to monitor the information from the load sensor **141** and may be further configured to identify when the initial separation **1005** occurs due to a spike in the information, such as a force measurement, that occurs at the time of the initial separation **1005**. The information provided by the load sensor **141** at the time of the initial separation

1005 can be used to determine (e.g., calculate) the bond strength between the leading peripheral edge **1919** of the first substrate **601** and the second substrate **603**. The bond strength can be used in a wide variety of ways. For instance, determining the bond strength can be used to help determine the specifications of the first substrate bonded to the second substrate. This information can be provided to vendors that may like this information for appropriate further processing of the first substrate. The bond strength can also be provided as feedback to the control device **143** for modifying a subsequent process of separating a subsequent first substrate from a subsequent second substrate. Indeed, a series of separation procedures may be assumed to involve substrates with similar bonding strength. As such, feedback of the bonding strength can be used to help fine tune the process to increase efficiency and effectiveness of separation (e.g., reducing time to initial separation, maintaining a minimum bend radius while separating, etc.).

[**0079**] After the step **1919** of peeling the leading peripheral edge **911**, the method can further include the step **1923** of completely removing the first substrate **601** from the second substrate **603**. In still another example, as shown in **FIGS. 11 and 12** the step **1923** of completely removing the first substrate **601** from the second substrate **603** comprises completely peeling the first substrate from the second substrate. Indeed, the vacuum attachment member **117** can be lifted wherein the arm **119** pivots in direction **135** about the float hinge **127** to such that the peel apparatus **101** achieves the open orientation. In the open orientation shown in **FIG. 12**, the first substrate **601** is completely peeled from the second substrate **603** even though the figure illustrates an outer corner of the first substrate **601** resting (without adhesion) on an outer portion of the second substrate **603**.

[**0080**] In some examples, during the step of peeling (e.g., initially peeling, partially peeling, completely peeling) the first substrate from the second substrate, the method can further include the step **1925** of controlling a bend radius “**R**” (see **FIG. 11**) of the first substrate **601**. For example, there may be desire to ensure that the first substrate **601** is not peeled in such a way that the bend radius is smaller than a predetermined minimum bend radius. The predetermined minimum bend radius may be a radius that the first substrate **601** may be safely bent without a significant probability of breaking or otherwise being damaged. In one example, the control device **143** may control the actuator **133** to provide a predetermined varying force “**F**” over time after initial separation **1005**. Varying the force “**F**” in a controlled manner over time can be designed to ensure that the bend radius “**R**” does not fall

below a predetermined minimum bend radius. In further examples, although not shown, a proximity sensor may be provided that senses the actual bend radius of the first substrate wherein the control device **143** can appropriately modify the force “**F**” applied by the actuator based on feedback from the proximity sensor.

[0081] In further examples, in addition to preselecting a minimum bend radius, the step **1925** of controlling the bend radius “**R**” can further include selecting a flexible membrane **917** to increase the effective stiffness of the first substrate **601** to maintain the bend radius “**R**” of the first substrate **601** above the minimum bend radius during a step of peeling (e.g., initially peeling, partially peeling, completely peeling) the first substrate from the second substrate. For instance, a dicing tape can be selected for the flexible membrane **917** that has a sufficient rigidity to adjust the effective rigidity of the first substrate **601** when applied across the entire second major surface **601b** of the first substrate **601**. The rigidity of the first substrate **601** may be adjusted by choosing the material and/or thickness of the dicing tape (including the backing and/or the adhesive), for example. Increasing the rigidity of the first substrate **601** can help the first substrate resist bending, and therefore help maintain a bend radius “**R**” above the predetermined minimum bend radius while peeling (e.g., initially peeling, partially peeling, completely peeling) the first substrate **601** from the second substrate **603**.

[0082] Once the step **1923** of completely removing the first substrate **601** from the second substrate **603** is complete, the method can end at any point of the process as indicated by arrows **1927**, **1929**, **1931** and **1933**. Before ending the method, in one example, the method can further continue with the optional step **1935** of processing the first substrate **601** as indicated by arrow **1937**. Indeed, further processing steps, may be carried out wherein the flexible membrane **917** may provide protection to the second major surface **601b** of the first substrate **601**. In further examples, the tab **1001** may be used to help process the first substrate (e.g., handle the first substrate) without gripping the first substrate that may otherwise damage the first substrate.

[0083] Before ending, the method can also include the step **1939** of removing the flexible membrane **917** from the first substrate **601**. Various removal techniques may be used depending on the characteristics of the adhesive used to bond the flexible membrane **917** to the first substrate **601**. In one example, the step **1939** of removing the flexible membrane **917** from the first substrate **601** can include exposing the flexible membrane to ultraviolet light to

release the flexible membrane **917** from the second major surface **601b** of the first substrate **601**, as when the adhesive of the flexible membrane is UV sensitive.

[0084] The method described with respect to **FIG. 19** and **FIGS. 1-12** can be carried out with a wide range of substrates. **FIGS. 13-15** illustrate another example that, unless otherwise noted, can include identical steps and/or equivalent steps discussed with respect to **FIG. 19** and **FIGS. 1-12** above. However, in the illustrated example of **FIGS. 13-15**, a first substrate **1301** comprises a carrier substrate and a second substrate **1302** (e.g., glass substrate or silicon wafer) can be vacuum attached to the vacuum plate **103**. Similarly as discussed above, the first substrate **1301** can be peeled (e.g., completely peeled) from the second substrate **1302** as shown in **FIGS. 13 and 15**.

[0085] **FIGS. 16-18** illustrate yet another example that, unless otherwise noted, can include identical steps and/or equivalent steps discussed with respect to **FIG. 19** and **FIGS. 1-15** above. However, in the illustrated example of **FIGS. 16-18**, a first substrate **1601a** comprises a first carrier substrate and a second substrate **1601b** comprises a second carrier substrate that can be vacuum attached to the vacuum plate **103**. An intermediate substrate **1603** can be sandwiched between and removably bonded to the first carrier substrate **1601a** and the second carrier substrate **1601b**. Similarly as discussed above, the first substrate **1601a** can be peeled (e.g., completely peeled) from the second substrate **1601b** by being peeled (e.g., completely peeled) from the intermediate substrate **1603**. Once completely peeled, the intermediate substrate **1603** may be peeled from the second carrier substrate **1601b** by one of the methods shown in **FIGS. 5-12 or FIGS. 13-15**. The intermediate substrate may be made of one or more layers. For example, the intermediate substrate may be a display panel including a backplane substrate, a cover substrate, and display elements disposed therebetween.

[0086] These are just a few examples of variations that can be made to the apparatus and method described above. Other various modifications and variations can be made without departing from the spirit and scope of the claims.

What is claimed is:

1. A method of processing a first substrate with a first major surface of the first substrate removably bonded to a first major surface of a second substrate, the method comprising the steps of:

(I) bonding a flexible membrane to a second major surface of the first substrate, wherein the flexible membrane includes a tab that extends off a leading peripheral edge of the first substrate; and

(II) peeling the leading peripheral edge of the first substrate from the second substrate by applying a force to the tab.

2. The method of claim 1, wherein the first substrate comprises a substrate selected from the group consisting of: a glass substrate and a silicon wafer.

3. The method of claim 1, wherein the first substrate includes a thickness of from about 100 microns to about 300 microns.

4. The method of claim 1, wherein the second substrate comprises a carrier substrate including a thickness of from about 300 microns to about 700 microns.

5. The method of claim 1, wherein the second substrate comprises a carrier substrate including a footprint that is larger than a footprint of the first substrate.

6. The method of any one of claims 1-5, wherein prior to step (II), further comprising the step of processing the first substrate while the first substrate is bonded to the second substrate.

7. The method of claim 6, wherein the step of processing the first substrate occurs prior to step (I).

8. The method of any one of claims 1-5, wherein the leading peripheral edge includes a length defined between a first lateral edge and a second lateral edge of the first substrate, and step (I) includes bonding the flexible membrane to the second major surface of the first substrate such that the flexible membrane extends along substantially the entire length of the leading peripheral edge.

9. The method of claim 8, wherein step (II) uniformly applies the force to the tab along the length of the leading peripheral edge.

10. The method of claim 8, wherein step (II) peels the leading peripheral edge of the first substrate from the second substrate substantially simultaneously along the entire length of the leading peripheral edge.

11. The method of any one of claims 1-5, wherein after step (II), further comprising the step of completely removing the first substrate from the second substrate.
12. The method of claim 11, wherein the step of completely removing the first substrate from the second substrate comprises completely peeling the first substrate from the second substrate.
13. The method of any one of claims 1-5, further comprising the steps of preselecting a minimum bend radius of the first substrate and selecting a flexible membrane to increase the effective stiffness of the first substrate to maintain a bend radius of the first substrate above the minimum bend radius while peeling the first substrate from the second substrate.
14. The method of any one of claims 1-5, further comprising the step of controlling a bend radius of the first substrate while peeling the first substrate from the second substrate.
15. The method of any one of claims 1-5, wherein step (I) bonds the flexible membrane to cover substantially the entire second major surface of the first substrate.
16. The method of any one of claims 1-5, wherein step (I) bonds the flexible membrane to the second major surface of the first substrate such that the tab extends a distance of from about 5 cm to about 20 cm off the leading peripheral edge of the first substrate.
17. The method of any one of claims 1-5, wherein after step (II), further comprising the step of removing the flexible membrane from the first substrate.
18. The method of claim 17, wherein the step of removing the flexible membrane from the first substrate includes exposing the flexible membrane to ultraviolet light to release the flexible membrane from the second major surface of the first substrate.
19. The method of any one of claims 1-5, wherein step (II) includes vacuum attaching the tab to a vacuum attachment member and then applying the force to the tab with the vacuum attachment member.
20. The method of any one of claims 1-5, further comprising the step of determining a bond strength between the leading peripheral edge of the first substrate and the second substrate based on information obtained during step (II).