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(54) **Title**: A GLASS-CARRIER ASSEMBLY AND METHODS FOR PROCESSING A FLEXIBLE GLASS SHEET

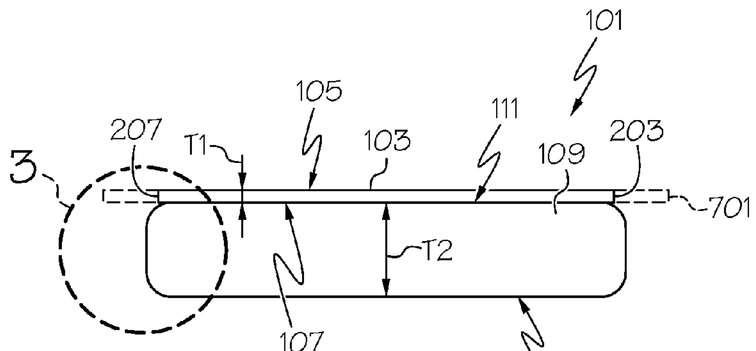

FIG. 1

(57) **Abstract**: A method of processing a flexible glass sheet having a thickness of equal to or less than 300 μm includes separating an outer edge portion of the flexible glass sheet from a bonded portion of the flexible glass sheet along a separation path while the bonded portion of the flexible glass sheet remains bonded with respect to a first major surface of a carrier substrate. The step of separating the outer edge portion provides the flexible glass sheet with a new outer edge extending along the separation path. A lateral distance between the new outer edge of the flexible glass sheet and an outer periphery of the first major surface of the carrier substrate is equal to or less than about 750 μm.

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A GLASS-CARRIER ASSEMBLY AND METHODS FOR PROCESSING A FLEXIBLE GLASS SHEET

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. 62/100,232 filed on January 6, 2015, the content of which is relied upon and incorporated herein by reference in its entirety.

FIELD

[0002] The present disclosure relates generally to methods for processing a flexible glass sheet and, more particularly, to methods for processing a flexible glass sheet including separating an outer edge portion from a bonded portion of the flexible glass sheet while the flexible glass sheet is bonded with respect to a first major surface of a carrier substrate.

BACKGROUND

[0003] There is interest in using thin, flexible glass ribbon in the fabrication of flexible electronics or other devices. Flexible glass sheets separated from the flexible glass ribbon can provide 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 ribbon is the ability to handle flexible glass sheets separated from the flexible glass ribbon.

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

[0005] After removing the flexible glass sheet from the carrier substrate, there is a desire to recycle the carrier substrate for future processing procedures with additional flexible glass sheets. However, current techniques of trimming the flexible glass sheet to size prior to bonding the trimmed flexible glass sheet to the carrier substrate typically generate glass particles that may contaminate the first major surface of the carrier substrate, thereby diminishing or destroying the utility of the carrier substrate for current or future processing procedures. Additionally, trimming the flexible glass sheet to size prior to bonding the trimmed flexible glass sheet to the carrier substrate may generate glass particles that contaminate the second major surface of the flexible glass sheet, which may give rise to problems in: reducing the strength of the bond between the flexible glass sheet and the carrier substrate; providing a path for ingress of process liquids into the flexible glass sheet/carrier interface during the processing of devices onto the flexible glass sheet; and/or debonding the flexible glass sheet from the carrier substrate as when the glass particles provide a bonding mechanism between the flexible glass sheet and the carrier, which bonding mechanism may lead to damage to the flexible glass sheet and/or carrier during a debonding process. Furthermore, there is a desire to provide a predetermined lateral distance between corresponding outer edges of the flexible glass sheet and the carrier substrate. However, current techniques of trimming the flexible glass sheet to size prior to bonding complicates precise positioning and bonding of the trimmed flexible glass sheet to the carrier substrate to achieve the predetermined lateral distance and/or a lateral distance within a predetermined range of lateral distances. Accordingly, there is a need for practical solutions for processing thin, flexible glass sheets.

SUMMARY

[0006] There are set forth methods configured to provide a flexible glass sheet bonded to a carrier substrate while preserving the utility of the carrier substrate for future processing procedures. Methods of the disclosure also simplify relative positioning between the edge(s) of the flexible glass sheet and the respective edge(s) of the carrier substrate by separating an outer edge of a bonded portion of the flexible glass sheet while the flexible glass sheet is bonded to the carrier substrate. In such a manner, a difficult task of aligning of a pre-trimmed flexible glass sheet with a carrier substrate can be avoided. Rather, an oversized flexible glass sheet may first be bonded with respect to the carrier substrate and then subsequently trimmed to a predetermined size and alignment. Accordingly, in some examples, the flexible glass sheet and the carrier substrate easily may be sized so that the flexible glass sheet is smaller than the carrier by up to 750 μm, at each point around the perimeter of the carrier.

[0007] In one example aspect, a method of processing a flexible glass sheet includes the step (I) of providing a flexible glass sheet including a first major surface and a second

major surface opposing the first major surface. The second major surface of the flexible glass sheet is bonded with respect to a first major surface of a carrier substrate and an outer edge portion of the flexible glass sheet protrudes beyond an outer periphery of the first major surface of the carrier substrate. A thickness between the first major surface and the second major surface of the flexible glass sheet is equal to or less than about 300 μm. The method then includes the step (II) of separating the outer edge portion from a bonded portion of the flexible glass sheet along a separation path while the bonded portion of the flexible glass sheet remains bonded with respect to the first major surface of the carrier substrate. The step of separating the outer edge portion provides the flexible glass sheet with a new outer edge extending along the separation path. A lateral distance between the new outer edge of the flexible glass sheet and the outer periphery of the first major surface of the carrier substrate is equal to or less than about 750 μm.

[0008] In one example of the aspect, step (I) further includes bonding the second major surface of the flexible glass sheet with respect to the first major surface of the carrier substrate. The second major surface of the flexible glass sheet that is bonded during step (I) has a larger surface area than a surface area of the first major surface of the carrier substrate. In one particular example, bonding during step (I) laterally circumscribes the first major surface of the carrier substrate with the outer edge portion of the flexible glass sheet.

[0009] In another example of the aspect, step (II) includes providing at least one defect in at least one of the first major surface and the second major surface of the flexible glass sheet on the separation path.

[0010] In one particular example of the aspect, the at least one defect includes a plurality of defects in the first major surface of the flexible glass sheet, and the plurality of defects are spaced apart from one another along the separation path. In one example, each defect of the plurality of defects extends from the first major surface to a depth below the first major surface of less than or equal to 20% of the thickness of the flexible glass sheet. In another example, the space between adjacent defects of the plurality of defects is within a range of from about 15 μm to about 25 μm. In still another example, step (II) further includes traversing a beam of electromagnetic radiation over the first major surface along the separation path to: (a) transform at least one of the plurality of defects into a full body crack intersecting the first major surface and the second major surface of the flexible glass sheet; and (b) propagate the full body crack through remaining defects of the plurality of defects along the separation path, thereby producing a full body separation of the outer edge portion from the bonded portion of the flexible glass sheet while the second major surface of the flexible glass sheet remains bonded to the first major surface of the carrier substrate.

[0011] In another particular example of the aspect, the at least one defect is provided in the second major surface of the flexible glass sheet and step (II) further includes traversing a beam of electromagnetic radiation over the first major surface along the separation path to: (a) transform the at least one defect into a full body crack intersecting the first major surface and the second major surface of the flexible glass sheet; and (b) propagate the full body crack through along the separation path, thereby producing a full body separation of the outer edge portion from the bonded portion of the flexible glass sheet while the second major surface of the flexible glass sheet remains bonded to the first major surface of the carrier substrate.

[0012] In yet another particular example of the aspect, step (II) further includes traversing a beam of electromagnetic radiation over the first major surface followed by a cooling stream of fluid along the separation path to: (a) transform the at least one defect into a full body crack intersecting the first major surface and the second major surface of the flexible glass sheet; and (b) propagate the full body crack along the separation path, thereby producing a full body separation of the outer edge portion from the bonded portion of the flexible glass sheet while the second major surface of the flexible glass sheet remains bonded to the first major surface of the carrier substrate. In one example, the at least one defect is provided in the first major surface of the flexible glass sheet.

[0013] In still another particular example, the at least one defect includes a scribe line in the first major surface of the flexible glass sheet along the separation path and wherein step (II) further includes applying a bending force to the outer edge portion to separate the outer edge portion from the bonded portion of the flexible glass sheet.

[0014] In a further example of the aspect, during step (II), the outer edge portion is bent relative to the bonded portion of the flexible glass sheet to place in tension the first major surface of the flexible glass sheet along the separation path.

[0015] In yet a further example of the aspect, the new outer edge of the flexible glass sheet has a B10 strength within a range of from about 150 MPa to about 200 MPa.

[0016] In still a further example of the aspect, the new outer edge of the flexible glass sheet laterally extends beyond the outer periphery of the first major surface of the carrier substrate.

[0017] In another example of the aspect, the outer periphery of the first major surface of the carrier substrate laterally extends beyond the new outer edge of the flexible glass sheet.

[0018] In another example of the aspect, the outer periphery of the first major surface of the carrier substrate laterally extends beyond the new outer edge of the flexible glass sheet by a distance up to about 250 μm.

[0019] In yet another example of the aspect, step (I) provides the second major surface of the flexible glass sheet with a larger surface area than a surface area of the first major surface of the carrier substrate. In one particular example, step (I) provides that the outer edge portion of the flexible glass sheet laterally circumscribes the first major surface of the carrier substrate.

[0020] In a further example of the aspect, after step (II), the method further includes the step (III) of releasing at least a portion of the flexible glass sheet from the carrier substrate by producing a concave curvature in the first major surface of the flexible glass sheet.

[0021] The aspect may be provided alone or in combination with any one or more of the examples of the aspect discussed above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The above and other features, aspects and advantages of the present invention are better understood when the following detailed description of the invention is read with reference to the accompanying drawings, in which:

[0023] **FIG. 1** is a perspective view of the flexible glass sheet bonded to the carrier substrate to form a glass-carrier assembly;

[0024] **FIG. 2** is a top view of the glass-carrier assembly of **FIG. 1**;

[0025] **FIG. 3** is an enlarged view of a portion of the glass-carrier assembly at view 3 of **FIG. 1**;

[0026] **FIG. 4** is an enlarged view of a portion of a glass-carrier assembly in accordance with another embodiment of the disclosure;

[0027] **FIG. 5** is an enlarged view of a portion of a glass-carrier assembly in accordance with still another embodiment of the disclosure;

[0028] **FIG. 6** illustrates a method of bonding the flexible glass sheet to the carrier substrate;

[0029] **FIG. 7** illustrates an oversized flexible glass sheet bonded to the carrier substrate;

[0030] **FIG. 8** is an enlarged view of a portion of an outer edge portion of the flexible glass sheet taken at view 8 of **FIG. 7**;

[0031] FIG. 9 is a plan view of the first major surface of the flexible glass sheet showing example separation paths;

[0032] FIG. 10 is a partial enlarged view long line 10-10 of **FIG. 9**;

[0033] FIG. 11 illustrates an example method of separating the outer edge portion of the glass ribbon by forming a plurality of defects in the first major surface of the flexible glass sheet;

[0034] FIG. 12 is a partial enlarged sectional view along line 12-12 of **FIG. 11** illustrating at least one of the plurality of defects being transformed into a full body crack;

[0035] FIG. 13 illustrates propagating the full body crack through a plurality of defects of **FIG. 11**;

[0036] FIG. 14 is a sectional view along line 14-14 of **FIG. 13** showing the full body crack propagating through the plurality of defects;

[0037] FIG. 15 is an enlarged view of a new outer edge formed by the full body crack of FIG. 14;

[0038] FIG. 16 is a Weibull distribution chart of strength of separated outer edge portions of the flexible glass sheets that were separated by a method similar to the method shown in **FIGS. 11-15**, and then subject to a two point bend test;

[0039] FIG. 17 illustrates another example method of separating the outer edge portion of the glass ribbon by forming a defect in the first major surface of the flexible glass sheet;

[0040] FIG. 18 is a partial enlarged side view of **FIG. 17** illustrating formation of the defect in the first major surface of the flexible glass sheet;

[0041] FIG. 19 is a partial enlarged side view similar to **FIG. 18** but showing the defect being transformed into a full body crack;

[0042] FIG. 20 illustrates propagating the full body crack along the separation path of **FIG. 17**;

[0043] FIG. 21 is a sectional view along line 21-21 of **FIG. 20** showing the full body crack propagating along the separation path;

[0044] FIG. 22 is a Weibull distribution chart of strength of separated outer edge portions of the flexible glass sheets that were separated by a method similar to the method shown in **FIGS. 17-21**, and then subject to a two point bend test;

[0045] FIG. 23 illustrates still another example method of separating the outer edge portion of the glass ribbon by forming a defect in the second major surface of the flexible glass sheet;

[0046] FIG. 24 illustrates a view similar to **FIG. 23** but showing the defect being transformed into a full body crack;

[0047] FIG. 25 illustrates propagating the full body crack along a separation path;

[0048] FIG. 26 is a sectional view along line 26-26 of **FIG. 25** showing the full body crack propagating along the separation path;

[0049] FIG. 27 illustrates yet another example method of separating the outer edge portion of the glass ribbon by forming a scribe line in the first major surface of the flexible glass sheet;

[0050] FIG. 28 illustrates breaking away the outer edge portion from the bonded portion fo the flexible glass sheet along the scribe line; and

[0051] FIG. 29 illustrates a method of at least partially peeling an edge of the flexible glass sheet from the carrier substrate.

DETAILED DESCRIPTION

[0052] The present invention will now be described more fully hereinafter with reference to the accompanying drawings in which example embodiments of the claimed invention are shown. Whenever possible, the same reference numerals are used throughout the drawings to refer to the same or like parts. However, the claimed invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. These example embodiments are provided so that this disclosure will be both thorough and complete, and will fully convey the scope of the claimed invention to those skilled in the art.

[0053] Methods of processing a flexible glass sheet can provide a glass-carrier assembly **101** including a flexible glass sheet **103** including a first major surface **105** and a second major surface **107** opposing the first major surface **105**. A thickness "**T1**" between the first major surface **105** and the second major surface **107** is equal to or less than about 300 μm, for example equal to or less than about 250 μm, for example equal to or less than about 200 μm, for example equal to or less than about 150 μm, for example equal to or less than about 100 μm, for example equal to or less than about 50 μm. In one example, the thickness **T1** can be within a range of from about 50 μm to about 300 μm, for example from about 50 μm to about 250 μm, for example from about 50 μm to about 200 μm, for example from about 50 µm to about 150 µm, for example from about 50 µm to about 100 µm. In further examples, the thickness **T1** can be within a range of from about 100 µm to about 300 µm, for example from about 100 µm to about 250 µm, for example from about 100 µm to about 200 µm, for example from about 100 µm to about 150 µm. In still further examples, the thickness **T1** can be within a range of from about 150 µm to about 300 µm, for example from about 150 µm to about 250 µm, for example from about 150 µm to about 200 µm. In yet further examples, the thickness **T1** can be within a range of from about 200 µm to about 300 µm, for example from about 200 µm to about 250 µm, for example from about 250 µm to about 300 µm.

[0054] The flexible glass sheet **103** can include at least one edge to provide the flexible glass sheet with a curvilinear (e.g., oval, circular, etc.) or polygonal (e.g., triangular, rectangular for example square, etc.) shape. For instance, as illustrated in **FIG. 2**, the flexible glass sheet **103** can further include four new outer edges **201, 203, 205, 207** produced by methods of the disclosure as discussed more fully below. The four new outer edges **201, 203, 205, 207** define the boundaries of the first major surface **105** and the second major surface **107** that may be arranged in the illustrated square shape although other shapes may be provided in further examples, for example, rectangular, polygonal, oval, or curvilinear.

[0055] The thin (i.e., less than or equal to 300 µm), flexible glass sheets **103** can be transparent and provide high optical transmission. The thin, flexible glass sheets **103** can further provide low surface roughness, high thermal and dimensional stability and a relatively low coefficient of thermal expansion. Therefore, thin, flexible glass sheets **103** can provide 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. Thin, flexible glass sheets of the present disclosure can be fabricated in any number of ways including down-drawn, up-draw, float, fusion, press rolling, or slot draw, glass forming process or other techniques. The flexible glass sheets may then be separated from the glass ribbon in process as the glass ribbon is being formed from the glass forming process. Alternatively, the flexible glass sheets may be separated from the glass ribbon at a different time or location (e.g., from a roll of previously-formed glass ribbon). Example thin, flexible glass sheets may be formed from Corning® Willow® glass available from Corning, Inc. although other types of thin, flexible glass sheets may be used in further examples of the disclosure.

[0056] As further illustrated in **FIG. 1**, the glass-carrier assembly **101** further includes a carrier substrate **109** with a first major surface **111** and a second major surface **113** opposing the first major surface **111**. A thickness "**T2**" between the first major surface **111** and the second major surface **113** is generally greater than the thickness T1, and may be from about 400 μm to about 1 mm, for example from about 400 μm to about 700 μm, for example from about 400 μm to about 600 μm although other thickness ranges may be used in further examples. The carrier substrate **109** may be provided as a wide range of materials for example glass, ceramic, glass ceramic or other materials. Depending on processing techniques or other requirements, the carrier substrate **109** may or may not transmit light and can therefore be at least partially or entirely transparent, translucent or opaque.

[0057] As further illustrated in **FIG. 2**, the carrier substrate **109** further includes outer edges **209, 211, 213, 215** that define an outer periphery **217** of the first major surface **111** of the carrier substrate **109**. For purposes of this application, the outer edges include the outermost surface **301** together with any beveled portions **303a, 303b**. As such, the outer periphery **217** of the first major surface **111** is considered the boundary where first major surface **111** begins to transition to the outer edge. In some examples, the outer periphery **217** can be a relatively sharp corner (e.g., 90° corner) where there is substantially no beveled portion but only the outermost surface **301** (e.g., a substantially flat outermost surface). Furthermore, as shown, in applications with a substantially flat first major surface **111**, the outer periphery **217** of the substantially flat first major surface **111** can be considered the boundary where the carrier substrate **109** leaves the plane of the substantially flat first major surface **111**. In some examples, the beveled portions may be provided to reduce stress concentrations. In one example, where the carrier substrate **109** has a thickness "**T2**" of about 500 μm, the lateral distance **305** between the outermost surface **301** and the outer periphery **217** can be from about 150 μm to about 250 μm although other distances **305** (e.g., from about 50 μm to about 750 μm) are possible depending on the thickness of the carrier substrate and other process considerations. In other embodiments, as wherein there is a relatively sharp corner for example, the distance **305** may be less than 50 microns, or close to zero, i.e., the outermost surface **301** may be substantially adjacent to the outer periphery **217**.

[0058] As shown in **FIGS 1-5**, the second major surface **107** of the flexible glass sheet **103** may be removably bonded with respect to the first major surface **111** of the carrier substrate **109**, thus forming the glass-carrier assembly **101**. For instance, in one example, a layer of adhesive material (see **601** in **FIG. 6**) may be used to removably (or temporarily) bond the second major surface **107** of the flexible glass sheet **103** to the first major surface **111** of the carrier substrate **109**. Moreover, other bonding techniques, for example, controlled hydrogen bonding may be used to temporarily bond the second major surface **107** of the flexible glass sheet **103** to the first major surface **111** of the carrier substrate **109**. The adhesive layer (or other bonding feature) may extend the entire length "**L1**" and may even extend over the entire surface area "**A2**" such that the entire first major surface **111** is bonded to the second major surface **107** of the flexible glass sheet **103**. In further examples, the adhesive layer (or other bonding feature) may extend a length "**L2**" that is less than the length "**L1**" such that only a central portion of the first major surface **111** is bonded to the second major surface **107** of the flexible glass sheet **103**.

[0059] In some examples, the carrier substrate **109** may have a geometrically similar or identical peripheral shape to the flexible glass sheet **103**. For example, although not shown, the carrier substrate **109** has an outer square shape that can be identical to the outer square shape of the flexible glass sheet **103**. In further examples, the carrier substrate **109** may have a shape that, although not identical, is geometrically similar to the shape of the flexible glass sheet **103**. For instance, as shown in the example embodiments of **FIGS. 1-4**, the carrier substrate **109** may have a shape that is larger but geometrically similar to the shape of the flexible glass sheet **103**. Providing a larger carrier substrate **109** can help protect the relatively fragile new outer edges **201, 203, 205, 207** of flexible glass sheet **103** from damage. In this instance, the flexible glass sheet **103** may be smaller than the carrier substrate **109** (around the entire periphery of the carrier substrate **109)** by up to about 750 microns, for example up to about 650 μm, for example up to about 550 μm, for example up to about 450 μm, for example up to about 350 μm, for example up to about 250 μm, for example up to about 150 μm, for example up to about 50 μm. Furthermore, as shown in the embodiment of **FIG. 5**, in some examples, the carrier substrate **109** may also have a shape that is smaller than the flexible glass sheet **103**.

[0060] More specifically, with reference to **FIG. 3**, methods of the disclosure a lateral distance "**Ld**" between the new outer edge of the flexible glass sheet and the outer periphery **217** of the first major surface **111** of the carrier substrate **109** is equal to or less than about 750 μm, for example less than about 650 μm, for example less than about 550 μm, for example less than about 450 μm, for example less than about 350 μm, for example less than about 250 μm, for example less than about 150 μm, for example less than about 50 μm.

[0061] In some examples, the lateral distance "**Ld**" can be within a range of from about 0 μm to about 750 μm, for example from about 0 μm to about 650 μm, for example from about 0 μm to about 550 μm, for example from about 0 μm to about 450 μm, for example from about 0 μm to about 350 μm, for example from about 0 μm to about 250 μm, for example from about 0 μm to about 150 μm, for example from about 0 μm to about 50 μm.

[0062] In further examples, the lateral distance "**Ld**" can be within a range of from about 50 μm to about 750 μm, for example from about 50 μm to about 650 μm, for example from about 50 μm to about 550 μm, for example from about 50 μm to about 450 μm, for example from about 50 μm to about 350 μm, for example from about 50 μm to about 250 μm, for example from about 50 μm to about 150 μm.

[0063] In still further examples, the lateral distance "**Ld**" can be within a range of from about 150 μm to about 750 μm, for example from about 150 μm to about 650 μm, for example from about 150 μm to about 550 μm, for example from about 150 μm to about 450 μm, for example from about 150 μm to about 350 μm, for example from about 150 μm to about 250 μm.

[0064] In additional examples, the lateral distance "**Ld**" can be within a range of from about 250 μm to about 750 μm, for example from about 250 μm to about 650 μm, for example from about 250 μm to about 550 μm, for example from about 250 μm to about 450 μm, for example from about 250 μm to about 350 μm.

[0065] In further examples, the lateral distance "**Ld**" can be within a range of from about 350 μm to about 750 μm, for example from about 350 μm to about 650 μm, for example from about 350 μm to about 550 μm, for example from about 350 μm to about 450 μm.

[0066] In yet further examples, the lateral distance "**Ld**" can be within a range of from about 450 μm to about 750 μm, for example from about 450 μm to about 650 μm, for example from about 450 μm to about 550 μm.

[0067] In further examples, the lateral distance "**Ld**" can be within a range of from about 550 μm to about 750 μm, for example from about 550 μm to about 650 μm. And in further examples, the lateral distance "**Ld**" can be within a range of from about 650 μm to about 750 μm.

[0068] As shown in **FIGS. 3 and 5**, the new outer edge **207** of the flexible glass sheet 103 laterally extends beyond the outer periphery **217** of the first major surface **111** of the carrier substrate **109** as shown by "**Ld**" in **FIGS. 3 and 5**. Alternatively, as shown in **FIG. 4**, the outer periphery **217** of the first major surface **111** of the carrier substrate 109 laterally extends beyond the new outer edge **207** of the flexible glass sheet **103** as shown by "**Ld**" in **FIG. 4**.

[0069] Methods of the disclosure can also provide the new outer edges of the flexible glass sheet **103** with a relatively high strength. Indeed, the outer edges of the flexible glass sheet can be produced with significantly reduced flaws, cracks or other imperfections that might otherwise serve as points of crack failure. Edge strength can be measured by a conventional two-point bend test. Multiple samples may be fabricated using the same edge-forming technique. The point at which each of the samples fails can be plotted on a Weibull distribution graph. Throughout the application, the "B10 strength" of the flexible glass sheet is the mean stress of failure of the flexible glass sheets where 10% of the sample is expected to fail. Based on two point bend tests conducted on the separated outer edge portions of the flexible glass sheets, methods of the disclosure are expected to provide the flexible glass sheets with a B10 strength of at least 150 MPa, for example at least 175 MPa, for example at least 200 MPa. In some examples, the B10 strength can be from about 150 MPa to about 200 MPa, for example from about 150 MPa to about 190 MPa, for example from about 150 MPa to about 180 MPa, for example from about 150 MPa to about 170 MPa, for example from about 150 MPa to about 160 MPa.

[0070] Methods of processing a flexible glass sheet will now be described, for example, to produce the alternative embodiments of the example glass-carrier assembly **101** discussed above.

[0071] The method can begin by providing the flexible glass sheet **103** including the first major surface **105** and the second major surface **107** opposing the first major surface **105**. The second major surface **107** of the flexible glass sheet **103** is temporarily bonded with respect to the first major surface **111** of the carrier substrate **109**. In one example, the method can begin with the flexible glass sheet **103** already bonded with respect to the carrier substrate **109** as shown in **FIG. 7**. For instance, the flexible glass sheet and carrier substrate may have already been bonded previously. Alternatively, as shown in **FIG. 6**, the method can include the step of temporarily bonding the second major surface **107** of the flexible glass sheet **103** with respect to the first major surface **111** of the carrier substrate **109**. Indeed, as discussed above for example, a layer of adhesive material **601** may be applied (e.g., to the first major surface **111** of the carrier substrate **109**). The specific mechanism of temporarily bonding the second major surface 1**07** to the first major surface **111** is not particularly important, and does not require an adhesive material. The flexible glass sheet **103** and the carrier substrate **109** can thereafter be pressed together to bond the second major surface **107** of the flexible glass sheet **103** to the first major surface **111** of the carrier substrate **109** as shown in **FIG. 7**.

[0072] As shown in **FIG. 6**, the second major surface **107** of the flexible glass sheet **103** includes a surface area "**A1**" that can be larger than a surface area "**A2**" of the first major surface **111** of the carrier substrate **109**. In fact, the flexible glass sheet **103** can be significantly oversized such that the oversized surface area of the flexible glass sheet is significantly greater than the final trimmed surface area of the flexible glass sheet. The oversized nature of the flexible glass sheet can simplify the step of bonding since exact alignment of the flexible glass sheet relative to the carrier substrate is not required. Rather, the desired relative dimensions may be provided by subsequent separation of an outer edge portion of the glass sheet after the glass sheet is mounted to the carrier substrate.

[0073] As shown in **FIGS. 7 and 8**, once the oversized flexible glass sheet is mounted relative to the carrier substrate, an outer edge portion **701** of the flexible glass sheet **103** protrudes beyond the outer periphery **217** of the first major surface **111** of the carrier substrate **109**. Stated another way, the outer edge portion **701** of the flexible glass sheet **103** is cantilevered from the first major surface **111** of the carrier substrate **109**. In some examples, the protrusion distance can be from about 15 mm to about 150 mm although other protrusion distances may be used in further examples. As further shown in hidden lines in **FIG. 2**, in some examples, the significant oversized nature of the flexible glass sheet allows a rough alignment between the flexible glass sheet and the carrier substrate such that the outer edge portion **701** of the flexible glass sheet **103** laterally circumscribes the first major surface **111** of the carrier substrate **109**. After the bonding is complete, the outer edge portion **701** can thereafter be removed to provide precise relative dimensions between the flexible glass sheet and the carrier substrate.

[0074] With initial reference to **FIGS. 9 and 10**, methods of the disclosure can further include the step of separating the outer edge portion **701** from a bonded portion **901** (temporarily bonded portion, wherein the flexible glass sheet **103** may be removed from the carrier substrate **109** after processing, for example, processing of devices onto the flexible glass sheet) of the flexible glass sheet **103** along a separation path **903, 905, 907, 911** while the bonded portion **901** of the flexible glass sheet **103** remains bonded with respect to the first major surface **111** of the carrier substrate **109**. In some examples, areas of the outer edge portion **701** may be removed sequentially in segments. For instance, one side of the outer edge portion **701** may be removed by separating along the separation path **903** including a central portion **903a** of the path and opposite end segments **903b, 903c** of the separation path **903**. Alternatively, the separation path may include a plurality of central segments **903a, 905a, 907a, 911a** without one or any of the end segments. Indeed, in some examples, separation may occur along a closed separation path in the form of a circumferential ring **903a, 905a, 907a, 911a** that removes a circumferential outer edge portion **701**.

[0075] Once separated along the separation path, the step of separating the outer edge portion **701** provides the flexible glass sheet **103** with the new outer edge(s) **201, 203, 205, 207** extending along the separation path(s). As shown in **FIG. 10**, as discussed previously, the lateral distance "**Ld**" between the new outer edge(s) **201, 203, 205, 207** of the flexible glass sheet **103** and the outer periphery **217** of the first major surface **111** of the carrier substrate **109** can be equal to or less than about 750 μm.

[0076] Various techniques can be employed to separate the outer edge portion **701** while providing relatively high quality new outer edge(s) **201, 203, 205, 207** that provide the flexible glass sheet **103** with a desired level of strength. In one example, the method of separating can include providing at least one defect in at least one of the first major surface **105** and the second major surface **107** of the flexible glass sheet **103** on the separation path(s) **903, 905, 907, 911**.

[0077] Providing the defect in the second major surface **107** can help promote separation in applications where the first major surface **105** is being heated with electromagnetic radiation (e.g., a CO_2 laser) along the separation path. Indeed, heating the first major surface **105** places the first major surface under compressive stress which results in the opposite second major surface **107** of the flexible glass sheet **103** being placed under tensile stress. As the flexible glass sheet is weaker in tension than compression, providing the defect in the second major surface **107** can promote separation. However, application of a defect in the second major surface may consequently weaken the area around the defect even after separation. There may be a desire to avoid weakness in the second major surface since the procedure of subsequently removing the flexible glass sheet may place the second major surface **107** under tensile stress. Indeed, as shown in **FIG. 29**, removal of the flexible glass sheet **103** may involve bending the flexible glass sheet such that the second major surface **107** of the flexible glass sheet **103** is placed in tension. As such, in another example, to avoid weakness in the second major surface **107**, the at least one defect may be provided in the first major surface **105** on the separation path(s) **903, 905, 907, 911**. As shown in **FIG. 29**, the first major surface **105** would be placed under compressive stress during a peeling procedure. As the flexible glass sheet is stronger under compression, weakness introduced by the defect in the first major surface **105** may be of relatively less concern.

[0078] **FIGS. 11-15** demonstrate just one example method of separating the outer edge portion **701** from the bonded portion **901** of the flexible glass sheet **103** along the separation paths **903, 905, 907, 911** while the bonded portion **901** of the flexible glass sheet **103** remains bonded with respect to the first major surface **111** of the carrier substrate **109**. As shown in **FIG. 11**, the at least one defect can comprise a plurality of defects **1101** in the first major surface **105** of the flexible glass sheet **103**, wherein the plurality of defects **1001** are spaced apart from one another by a distance **1103** along the separation paths **903, 905, 907, 911**. In one example, the plurality of defects can be created by an ultraviolet laser **1105** configured to move along alternate directions **1107** along the separation paths **903, 905, 907, 911**.

[0079] In some examples, each defect of the plurality of defects **1101** can extend from the first major surface **105** to a depth **1501** below the first major surface **105** of less than or equal to 20% of the thickness **T1** of the flexible glass sheet, for example less than or equal to 10% of the thickness **T1** of the flexible glass sheet. In addition or alternatively, the distance **1103** between adjacent defects of the plurality of defects **1101** is within a range of from about 15 μm to about 25 μm, for example, about 20 μm.

[0080] As shown in **FIGS. 11-14**, the method can further include the step of traversing a beam **1109** of electromagnetic radiation along a direction **1111** over the first major surface **105** of the flexible glass sheet **103** along the separation paths **903, 905, 907, 911**. In one example, the electromagnetic radiation is provided by a CO_2 laser **1201** although other laser types may be used in further examples. As shown in **FIG. 12**, the beam **1109** of electromagnetic radiation transforms at least one defect **1101a** of the plurality of defects **1101** into a full body crack **1203** intersecting the first major surface **105** and the second major surface **107** of the flexible glass sheet **103**. As shown in **FIGS. 13-15**, the beam **1109** of electromagnetic radiation can continue to traverse along the direction **1111** over the first major surface **105** of the flexible glass sheet **103** along the separation paths **903, 905, 907, 911** to propagate the full body crack **1203** through remaining defects of the plurality of defects **1001**. Once the path is complete, as shown in **FIG. 2**, a full body separation of the outer edge portion **701** (removed and shown in hidden lines in **FIG. 2**) from the bonded portion **901** of the flexible glass sheet **103** while the second major surface **107** of the flexible glass sheet **103** remains bonded to the first major surface **111** of the carrier substrate **109**.

[0081] FIG. 16 is a Weibull distribution of 30 samples of separated outer edge portions **701** that were separated by methods similar to the methods shown and discussed with respect to **FIGS. 11-15**, and then subject to a two-point bend test. The vertical axis of the Weibull distribution is percent probability of failure and the horizontal axis is the maximum strength in MPa. As can be seen by the horizontal dashed line at 10%, the B10 strength of the separated outer edge portions **701**, and consequently the expected strength of the trimmed flexible glass sheets, can be within a range of from about 150 MPa to about 200 MPa. The outer range lines **1601**, **1603** intersect the 10% probability at **P1** (about 154 MPa) and **P2** (about 194 MPa) wherein the mean line **1605** intersects the 10% probability at **P3** (about 175 MPa). The tests that produced the 30 samples of the outer edge portions used in the two-point bend test included using an ultraviolet laser to produce a plurality of defects **1101** spaced a distance **1103** of 20 μm, a diameter of 8 μm and a depth **1501** of 10 μm.

[0082] FIGS. 17-21 illustrate another example method of separating the outer edge portion **701** from the bonded portion **901** of the flexible glass sheet **103** along the separation paths **903, 905, 907, 911** while the bonded portion **901** of the flexible glass sheet **103** remains bonded with respect to the first major surface **111** of the carrier substrate **109**. As shown a first defect **1701** can be provided in the first major surface 105 of the glass sheet although the first defect may be provided in the second major surface **107** in further examples. The first defect **1701** can be produced using various methods. For example, the first defect **1701** produced by a laser pulse (e.g., ultraviolet laser) or by a mechanical tool (see **1801** in **FIG. 18**) for example a scribe, scoring wheel, diamond tip, indenter, etc.

[0083] As shown in **FIGS. 20-21**, the method can further include the step of traversing a beam **1109** of electromagnetic radiation over the first major surface **105**. The beam **1109** of electromagnetic radiation can be produced by a laser and can produce the heated region **1109** shown in **FIG. 20**. As further shown in **FIG. 20**, the beam **1109** of electromagnetic radiation is followed by a cooling stream **2103** of fluid along the separation paths **903, 905, 907, 911**. The cooling fluid can comprise a liquid, gas or combination of liquid and gas. For instance, the cooling fluid can comprise a cooling stream of mist including air and water. The application of the cooling stream **2103** produces a cooled region on the first major surface **105** of the flexible glass sheet **103** that is substantially lower in temperature than the heated region produced by the beam **1109** of electromagnetic radiation.

As a result of this temperature difference, a thermal stress is generated in the flexible glass sheet **103** that causes the first defect **1701** to transform into a full body crack **1901** intersecting the first major surface **105** and the second major surface **107** of the flexible glass sheet **103**.

[0084] As shown in **FIGS. 20 and 21**, the method can traverse the beam **1109** of electromagnetic radiation followed by the cooling stream **2103** in direction **2001** to propagate the full body crack **1901** along the separation paths **903, 905, 907, 911**, thereby producing a full body separation of the outer edge portion **701** from the bonded portion **901** of the flexible glass sheet **103** while the second major surface **107** of the flexible glass sheet **103** remains bonded to the first major surface **111** of the carrier substrate **109**.

[0085] In some examples, the laser used to produce the beam **1109** of electromagnetic radiation can comprise a CO_2 laser. In some examples, the CO_2 laser can be operated with a power of from about 5 W to about 400 W, for example 10 W to about 200 W, for example 15 W to about 100 W, for example 20 W to 75 W. The maximum dimension of the beam spot (e.g., see elliptical spot **2101** of the beam in **FIG. 20)** can be within a range of from about 2 mm to about 50 mm, for example from about 2 mm to about 30 mm, for example from about 2 mm to about 20 mm, for example, from about 5 mm to about 15 mm, for example about 10 mm to about 11 mm.

[0086] Prior to or during forming the first defect **1701** or prior to or during transforming of the first defect **1701** into the full body crack **1901**, as shown in hidden lines in **FIGS. 18 and 19**, the outer edge portion **701** may be bent relative to the bonded portion **901** of the flexible glass sheet **103** to place the first major surface **105** of the flexible glass sheet **103** along the separation path in tension. Placing the first major surface **105** in tension amplifies the significance of the first defect **1701**, making it easier to transform the first defect into the full body crack or to propagate the full body crack along the separation path.

[0087] **FIG. 22** is a Weibull distribution of 30 samples of separated outer edge portions **701** that were separated by methods similar to the methods shown and discussed with respect to **FIGS. 17-21**, and then subject to a two-point bend test. The vertical axis in the Weibull distribution is percent probability of failure and the horizontal axis is the maximum strength in MPa. As can be seen by the horizontal dashed line at 10%, the B10 strength of the separated outer edge portions **701**, and consequently the expected strength of the trimmed flexible glass sheets, can be within a range of from about 125 MPa to about 225 MPa, and for example from about 150 MPa to about 200 MPa. A first outer range line **2201**

intersects the 10% probability at **P4** between 125 MPa and 150 MPa. A second outer range line **2203** intersects the 10% probability at **P5** between 200 MPa and 250 MPa. The mean line **2205** intersects the 10% probability at **P6** (about 175 MPa).

[0088] FIGS. 23-26 illustrate still another example method of separating the outer edge portion **701** from the bonded portion **901** of the flexible glass sheet **103** along the separation paths **903, 905, 907, 911** while the bonded portion **901** of the flexible glass sheet **103** remains bonded with respect to the first major surface **111** of the carrier substrate **109**. As shown in **FIG. 23**, a defect **2301** can be formed in the second major surface **107** of the flexible glass sheet **103** rather than the first major surface **105** as shown in **FIG. 18**. Like the embodiment of **FIG. 18**, the defect can be produced using various methods. For example, the defect **2301** produced by a laser pulse (e.g., ultraviolet laser) or by the mechanical tool (see **1801** in **FIG. 23**) for example a scribe, scoring wheel, diamond tip, indenter, etc.

[0089] As the defect **2301** of **FIG. 23** is formed in the second major surface **107**, the cooling stream of **FIGS. 20-21** may not be necessary. Indeed, as mentioned previously, heating the first major surface **105** can cause tension in the second major surface. Such tension resulting from traversing the beam **1109** of electromagnetic radiation over the first major surface **105** may be sufficient alone to transform the defect **2301** into a full body crack **2401** (see **FIG. 24**) intersecting the first major surface **105** and the second major surface **107** of the flexible glass sheet **103**.

[0090] As shown in **FIG. 25** the method can traverse a beam **1109** of electromagnetic radiation in direction **2501** to propagate the full body crack **2401** along the separation paths **903, 905, 907, 911**, thereby producing a full body separation of the outer edge portion **701** from the bonded portion **901** of the flexible glass sheet **103** while the second major surface **107** of the flexible glass sheet **103** remains bonded to the first major surface **111** of the carrier substrate **109**.

[0091] In some examples, the laser used to produce the beam **1109** of electromagnetic radiation can comprise a CO_2 laser. In some examples, the CO_2 laser can be operated with a power of from about 5 W to about 400 W, for example 10 W to about 200 W, for example 15 W to about 100 W, for example 50 W to 80 W, for example 20 W to 75 W. The maximum dimension of the beam spot (e.g., see elliptical spot **2101** of the beam in **FIG. 25**) can be within a range of from about 2 mm to about 50 mm, for example from about 2 mm to about 30 mm, for example from about 2 mm to about 20 mm, for example, from about 5 mm to about 15 mm, for example about 10 mm to about 11 mm.

[0092] FIGS. 27 and 28 illustrate yet another example method of separating the outer edge portion **701** from the bonded portion **901** of the flexible glass sheet **103** along the separation paths **903, 905, 907, 911** while the bonded portion **901** of the flexible glass sheet **103** remains bonded with respect to the first major surface **111** of the carrier substrate **109**. As shown, the at least one defect can comprise a scribe line **2701** in the first major surface **105** of the flexible glass sheet **103** along the separation path **903**. The scribe line **2701** may extend over a substantial distance, for example the entire distance, between opposed edges **2703a, 2703b** and may be produced by a laser pulse (e.g., ultraviolet laser) or by a mechanical tool (see **1801** in **FIG. 27**) for example a scribe, scoring wheel, diamond tip, indenter, etc.

[0093] As shown in **FIG. 28**, the method can further apply a bending force "**F**" to the outer edge portion **701** to separate the outer edge portion **701** from the bonded portion **901** of the flexible glass sheet **103**. Producing a scribe line along a substantial distance, for example the entire distance, between opposed edges can result in corresponding damage that may reduce bending strength of the flexible glass sheet. However, since the damage is limited to the first major surface **105**, the weakened areas may not manifest itself in failure during subsequent peeling of the flexible glass sheet **103** from the carrier substrate **109**.

[0094] As shown in **FIG. 29**, sometime after separating the outer edge portion(s) from the bonded portion **901** of the flexible glass sheet **103**, the method can optionally include the step of releasing at least a portion of the flexible glass sheet **103** from the carrier substrate **109** by producing a concave curvature **2903** in the first major surface **105** of the flexible glass sheet **103**. The concave curvature **2903** results in the first major surface **105** being placed in compression, thereby minimizing any weakening along the first major surface **105** of the flexible glass sheet **103** that may have occurred when forming the scribe line **2701**. In just one example a force **2901** may be applied to an edge portion of the flexible glass sheet **103** to promote initial or entire peeling of the flexible glass sheet from the carrier substrate.

[0095] After forming the glass-carrier assembly **101** of **FIGS. 1-4** and before debonding the flexible glass sheet as shown in **FIG. 29**, the flexible glass sheet **103** may undergo further processing techniques. For example, liquid crystal growth, thin film deposition, polarizer bond or other techniques may be performed. Moreover, the flexible glass sheet **103** may temporarily be supported by the relatively rigid carrier substrate to facilitate processing of the flexible glass sheet with current manufacturing processes and devices configured to handle relatively rigid and relatively thick glass sheet.

[0096] It will be apparent to those skilled in the art that various modifications and variations can be made to the present invention without departing from the spirit and scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. A method of processing a flexible glass sheet comprising:

(I) providing a flexible glass sheet including a first major surface and a second major surface opposing the first major surface, wherein the second major surface of the flexible glass sheet is bonded with respect to a first major surface of a carrier substrate and an outer edge portion of the flexible glass sheet protrudes beyond an outer periphery of the first major surface of the carrier substrate, and a thickness between the first major surface and the second major surface of the flexible glass sheet is equal to or less than about 300 μm; and then

(II) separating the outer edge portion from a bonded portion of the flexible glass sheet along a separation path while the bonded portion of the flexible glass sheet remains bonded with respect to the first major surface of the carrier substrate, wherein the step of separating the outer edge portion provides the flexible glass sheet with a new outer edge extending along the separation path, wherein a lateral distance between the new outer edge of the flexible glass sheet and the outer periphery of the first major surface of the carrier substrate is equal to or less than about 750 μm.

2. The method of claim 1, wherein step (I) further includes bonding the second major surface of the flexible glass sheet with respect to the first major surface of the carrier substrate, wherein the second major surface of the flexible glass sheet being bonded during step (I) has a larger surface area than a surface area of the first major surface of the carrier substrate.

3. The method of claim 2, wherein bonding during step (I) laterally circumscribes the first major surface of the carrier substrate with the outer edge portion of the flexible glass sheet.

4. The method of any one of claims 1-3, wherein step (II) includes providing at least one defect in at least one of the first major surface and the second major surface of the flexible glass sheet on the separation path.

5. The method of claim 4, wherein the at least one defect comprises a plurality of defects in the first major surface of the flexible glass sheet, and the plurality of defects are spaced apart from one another along the separation path.

6. The method of claim 5, wherein each defect of the plurality of defects extends from the first major surface to a depth below the first major surface of less than or equal to 20% of the thickness of the flexible glass sheet.

7. The method of claim 5 or claim 6, wherein the space between adjacent defects of the plurality of defects is within a range of from about 15 μm to about 25 μm.

8. The method of any one of claims 5-7, wherein step (II) further includes traversing a beam of electromagnetic radiation over the first major surface along the separation path to:

(a) transform at least one of the plurality of defects into a full body crack intersecting the first major surface and the second major surface of the flexible glass sheet; and

(b) propagate the full body crack through remaining defects of the plurality of defects along the separation path, thereby producing a full body separation of the outer edge portion from the bonded portion of the flexible glass sheet while the second major surface of the flexible glass sheet remains bonded to the first major surface of the carrier substrate.

9. The method of claim 4, wherein the at least one defect is provided in the second major surface of the flexible glass sheet and step (II) further includes traversing a beam of electromagnetic radiation over the first major surface along the separation path to:

(a) transform the at least one defect into a full body crack intersecting the first major surface and the second major surface of the flexible glass sheet; and

(b) propagate the full body crack along the separation path, thereby producing a full body separation of the outer edge portion from the bonded portion of the flexible glass sheet while the second major surface of the flexible glass sheet remains bonded to the first major surface of the carrier substrate.

10. The method of claim 4, wherein step (II) further includes traversing a beam of electromagnetic radiation over the first major surface followed by a cooling stream of fluid along the separation path to:

(a) transform the at least one defect into a full body crack intersecting the first major surface and the second major surface of the flexible glass sheet; and

(b) propagate the full body crack along the separation path, thereby producing a full body separation of the outer edge portion from the bonded portion of the flexible glass sheet while the second major surface of the flexible glass sheet remains bonded to the first major surface of the carrier substrate.

11. The method of claim 10, wherein the at least one defect is provided in the first major surface of the flexible glass sheet.

12. The method of claim 4, wherein the at least one defect comprises a scribe line in the first major surface of the flexible glass sheet along the separation path and wherein step (II) further includes applying a bending force to the outer edge portion to separate the outer edge portion from the bonded portion of the flexible glass sheet.

13. The method of any one of claims 1-3, 5-8, 10 and 11, wherein during step (II), the outer edge portion is bent relative to the bonded portion of the flexible glass sheet to place the first major surface of the flexible glass sheet along the separation path in tension.

14. The method of any one of claims 1-13, wherein the new outer edge of the flexible glass sheet has a B10 strength within a range of from about 150 MPa to about 200 MPa.

15. The method of any one of claims 1-14, wherein the new outer edge of the flexible glass sheet laterally extends beyond the outer periphery of the first major surface of the carrier substrate.

16. The method of any one of claims 1-14, wherein the outer periphery of the first major surface of the carrier substrate laterally extends beyond the new outer edge of the flexible glass sheet.

17. The method of any one of claims 1-14 and 16, wherein the outer periphery of the first major surface of the carrier substrate laterally extends beyond the new outer edge of the flexible glass sheet by a distance up to about 250 μm.

18. The method of any one of claims 1-17, wherein step (I) provides the second major surface of the flexible glass sheet with a larger surface area than a surface area of the first major surface of the carrier substrate.

19. The method of claim 18, wherein step (I) provides that the outer edge portion of the flexible glass sheet laterally circumscribes the first major surface of the carrier substrate.

20. The method of any one of claims 1-19, wherein after step (II), further comprising the step (III) of releasing at least a portion of the flexible glass sheet from the carrier substrate by producing a concave curvature in the first major surface of the flexible glass sheet.

21. A glass-carrier assembly comprising:

a flexible glass sheet comprising a first major surface and a second major surface opposing the first major surface, a thickness between the first major surface and the second major surface equal to or less than 300 µm;

a carrier substrate comprising a first major surface and a second major surface opposing the first major surface of the carrier substrate, and a perimeter, the first major surface of the carrier substrate being temporarily bonded to the second major surface of the flexible glass sheet,

wherein the flexible glass sheet is smaller than the carrier substrate by up to 750 microns at each point around the perimeter.

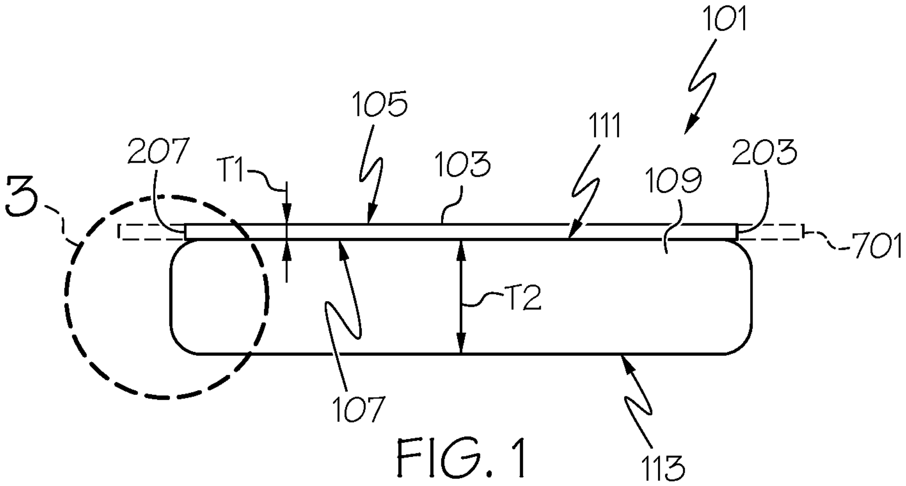

101
105
111
207
T1
103
109
203
3
701
T2
107
113

FIG. 1

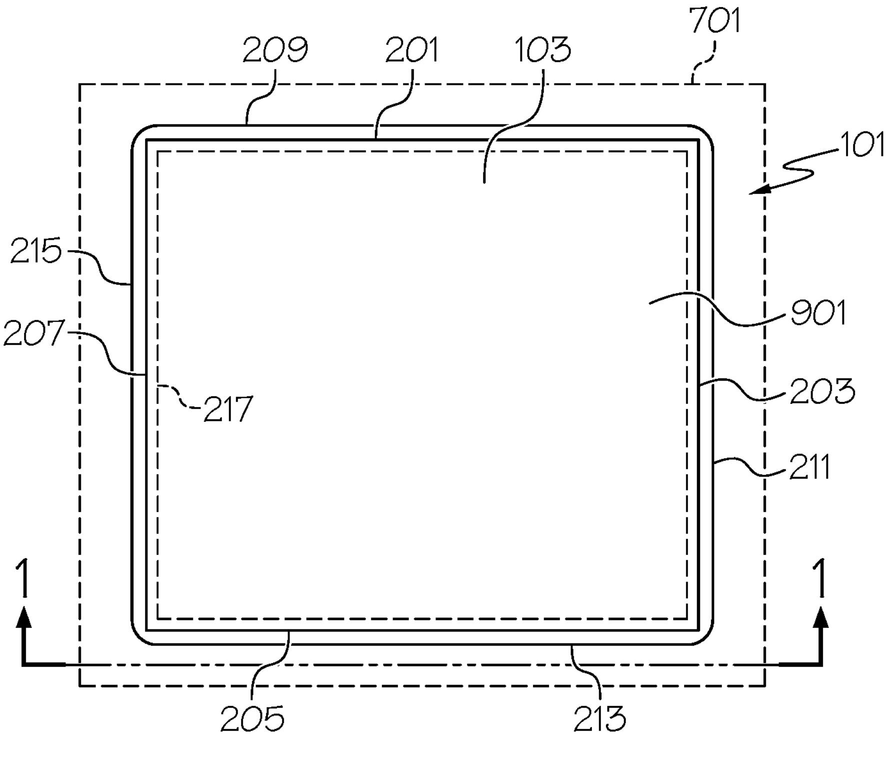

701
209
201
103
101
215
901
207
217
203
211
1
1
205
213

FIG. 2

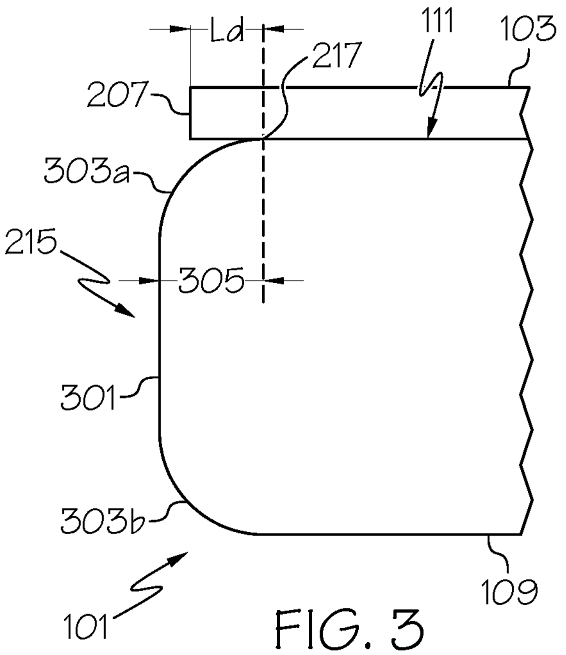


FIG. 3

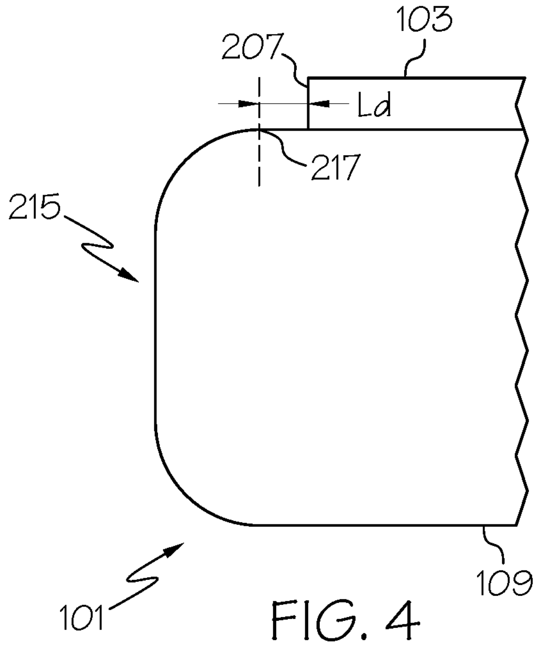


FIG. 4

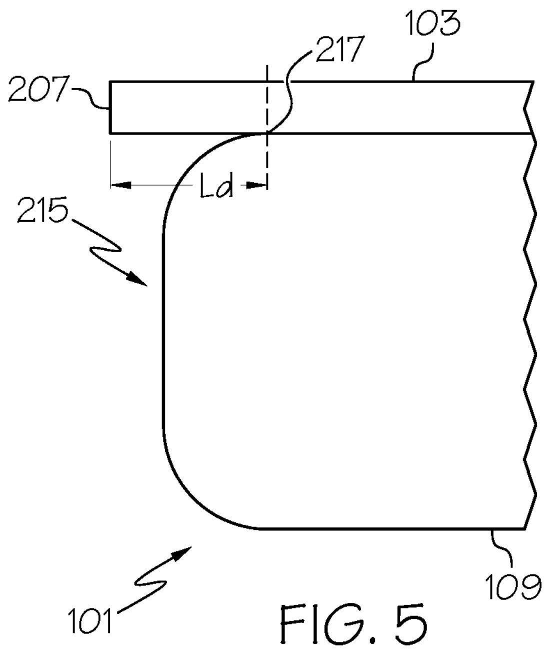


FIG. 5

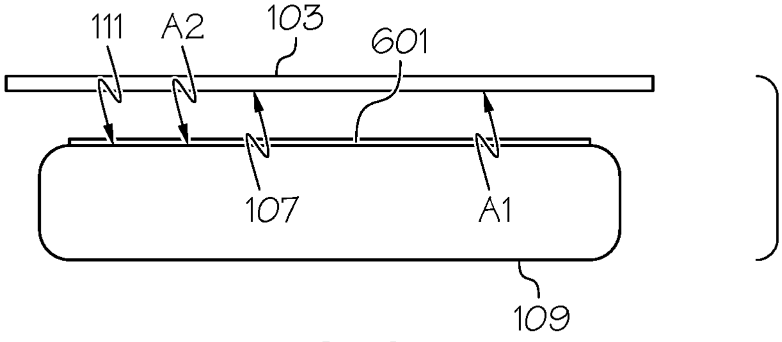


FIG. 6

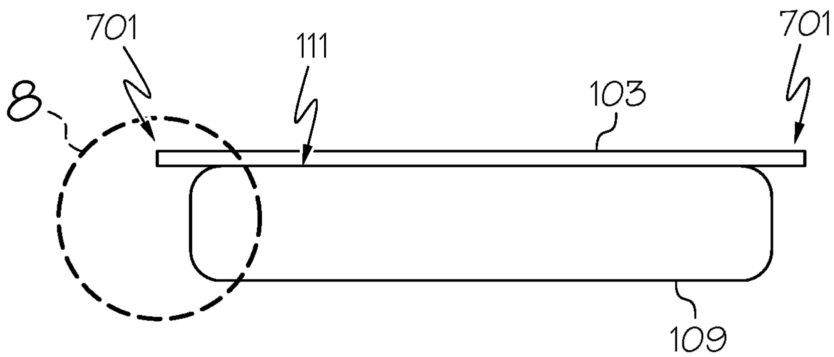


FIG. 7

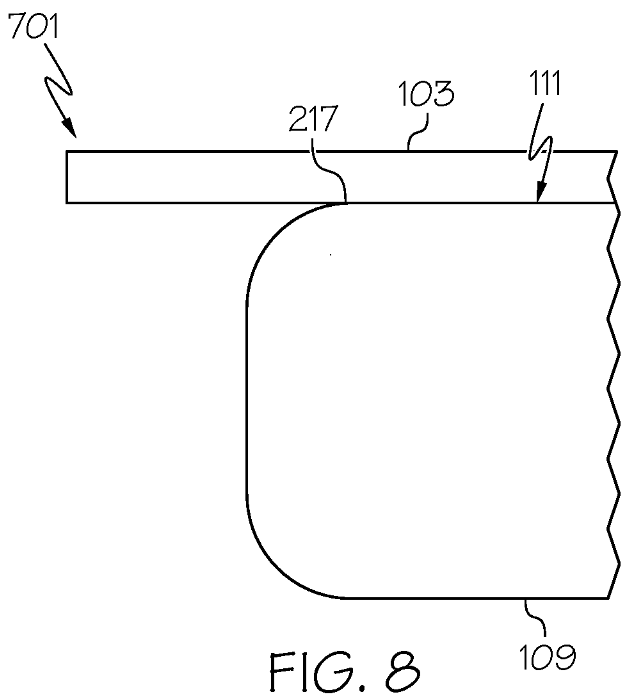


FIG. 8

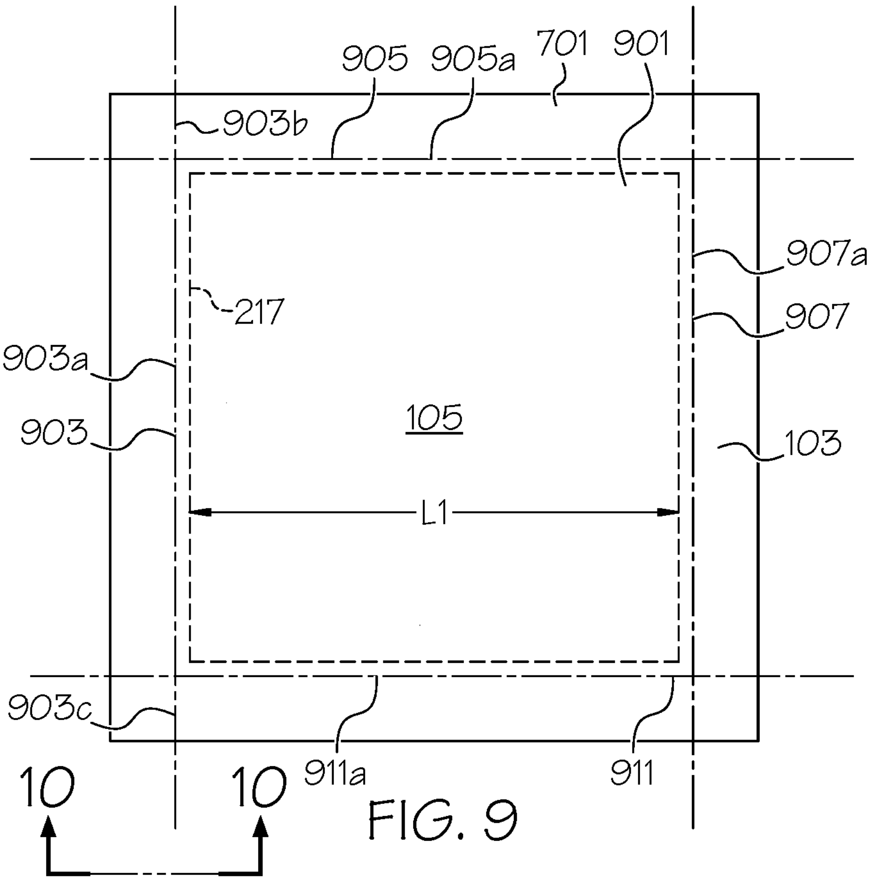
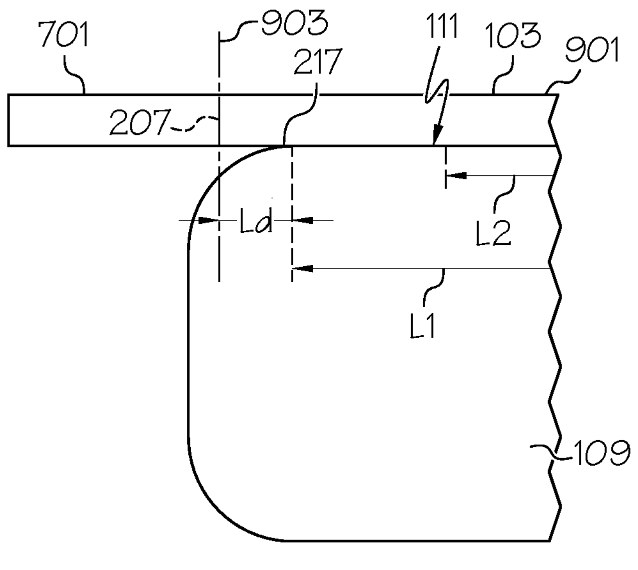

905
905a
701
901
903b
907a
217
907
903a
105
903
103
L1
903c
911a
911
10
10

FIG. 9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Ld
L2
L1
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FIG. 10

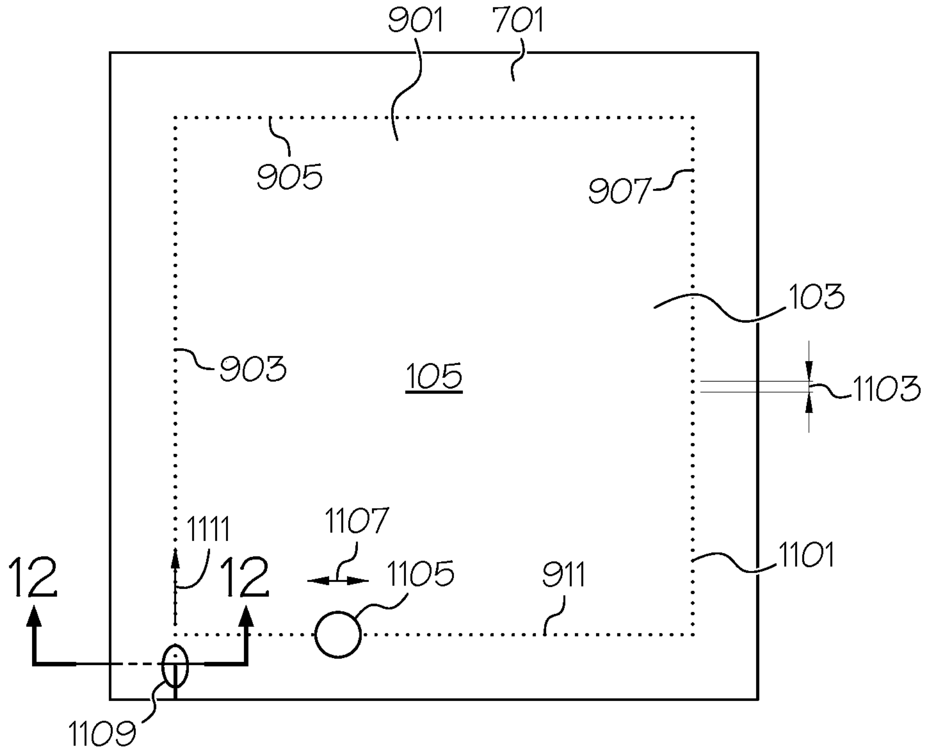
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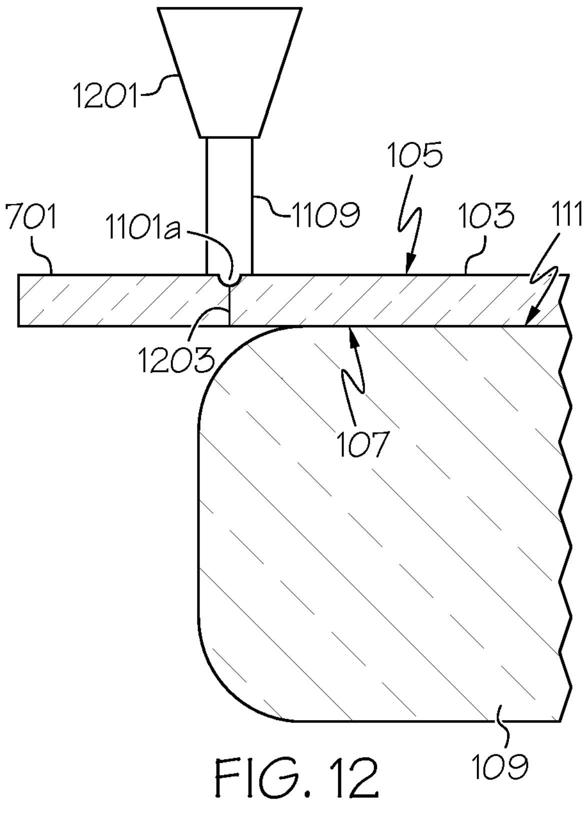
FIG. 11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109

FIG. 12

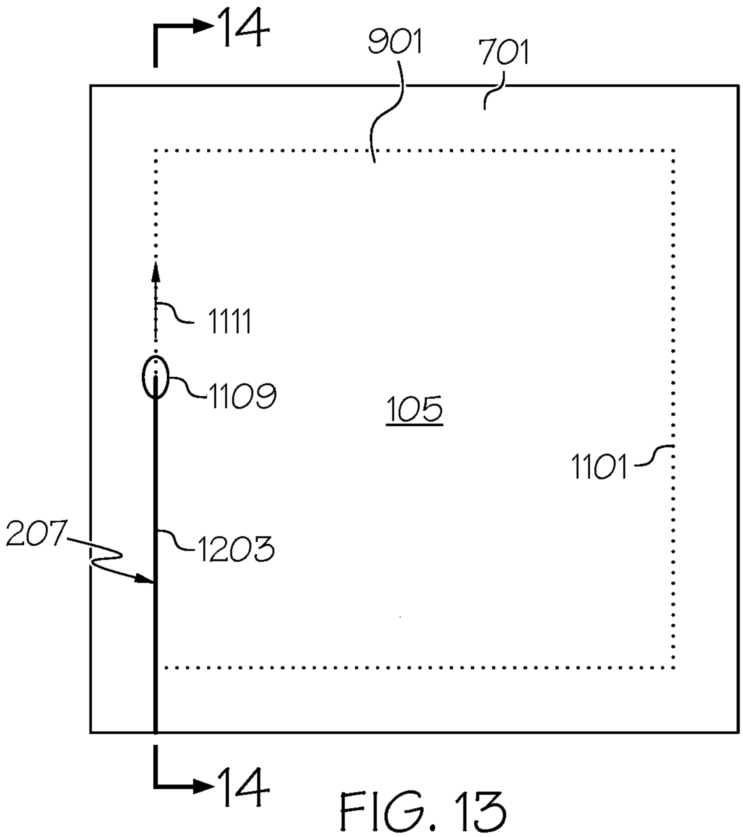
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FIG. 13

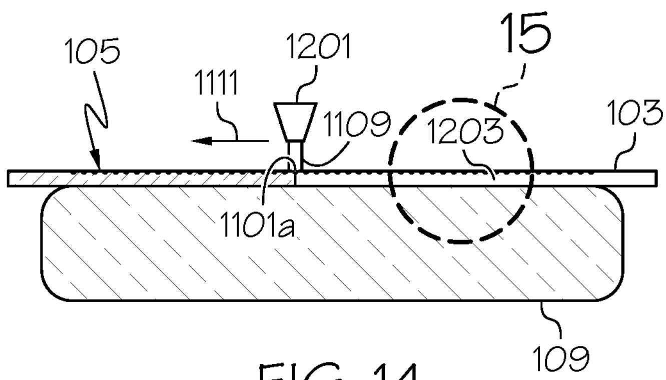
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FIG. 14

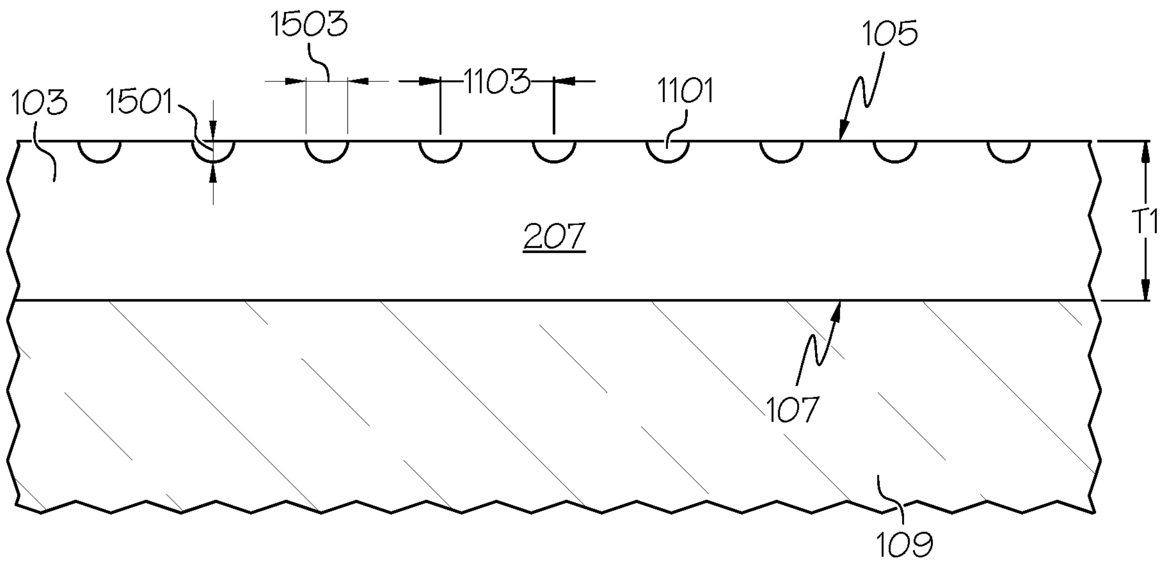
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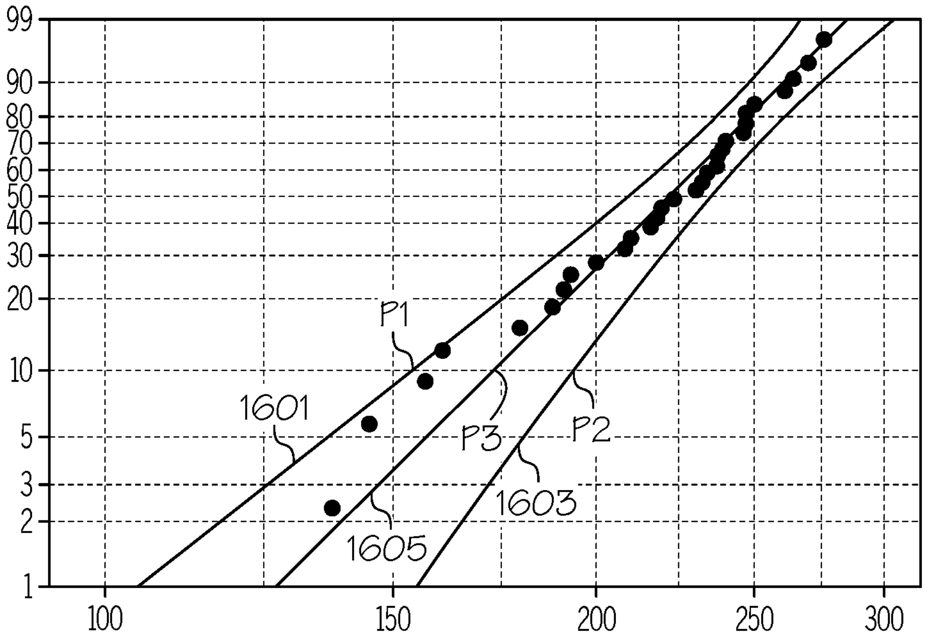
FIG. 15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P1
1601
P3
P2
1603
1605

FIG. 16

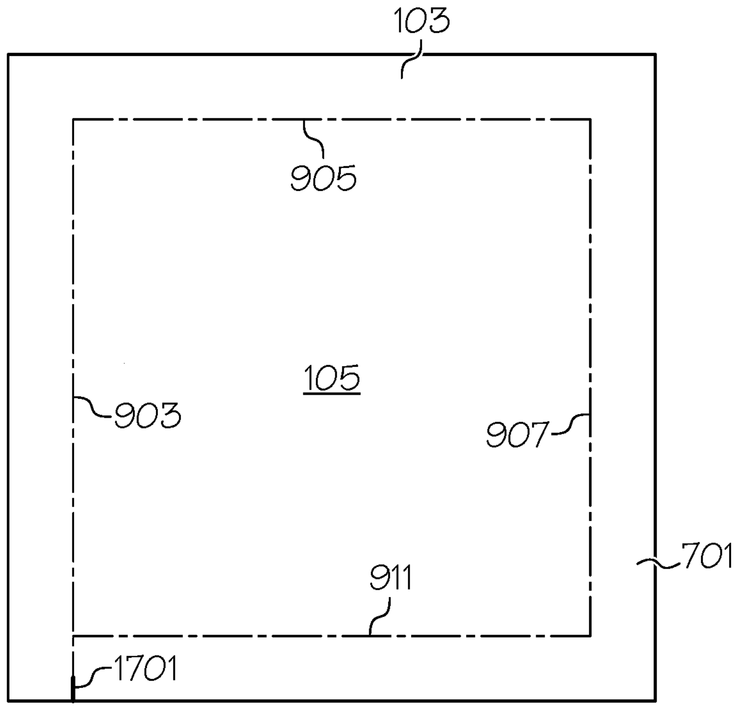


FIG. 17

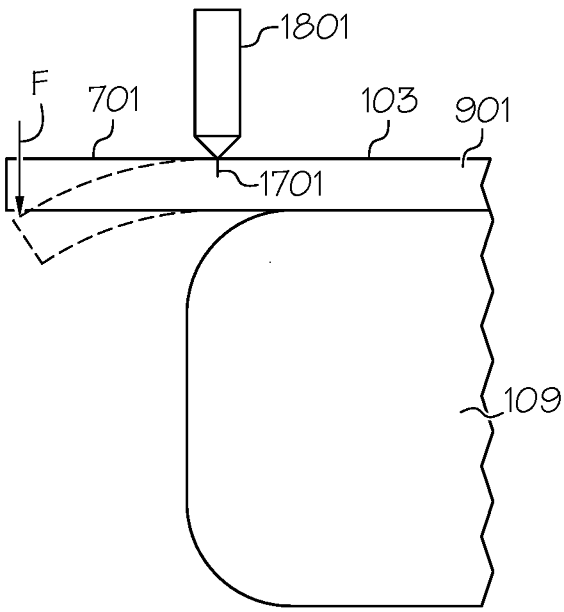


FIG. 18

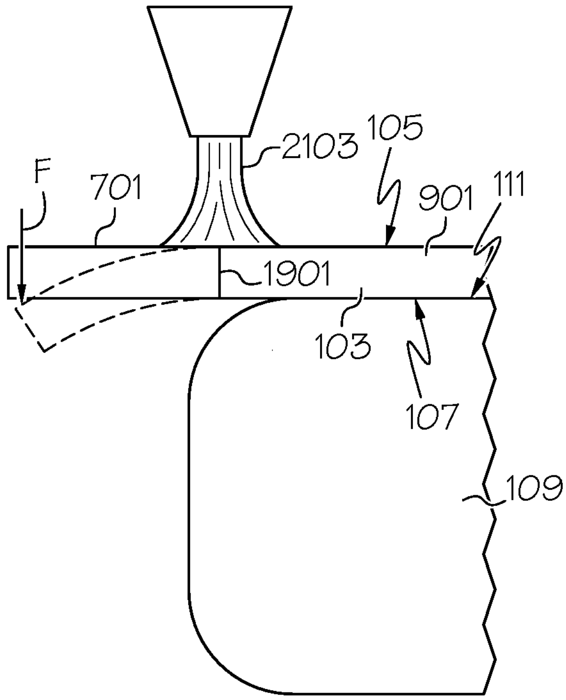
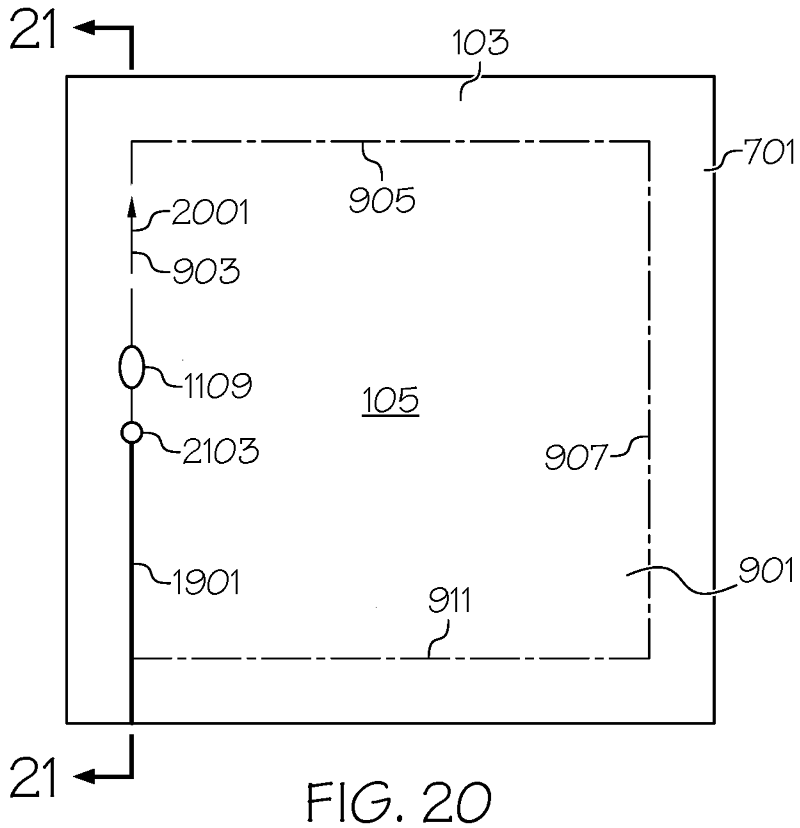


FIG. 19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2001
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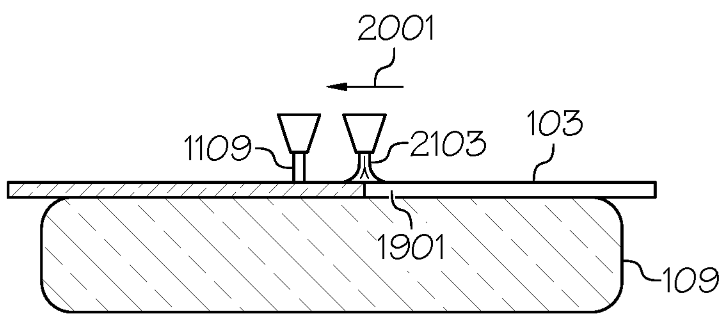
901
911
21

FIG. 20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2103
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FIG. 21

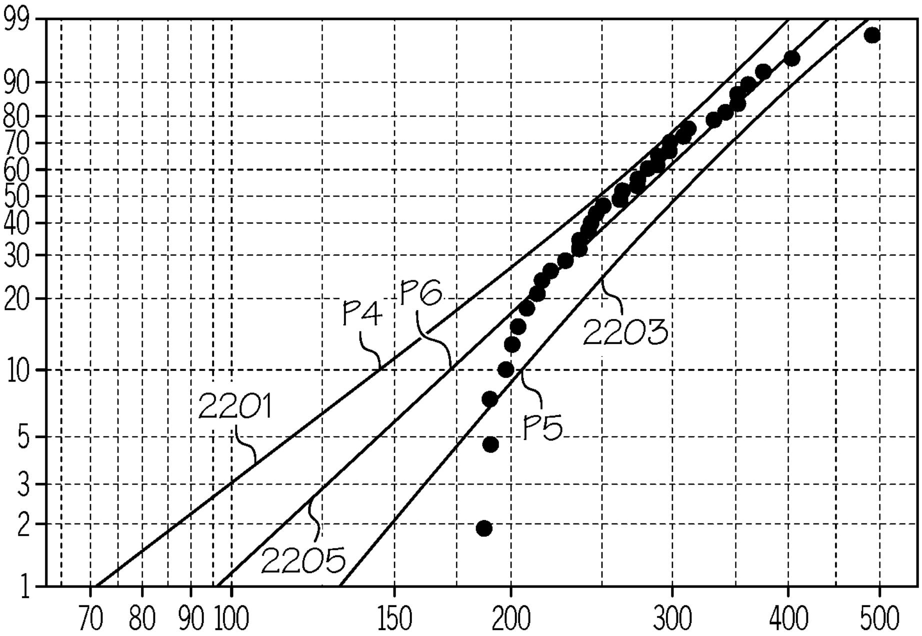

FIG. 22

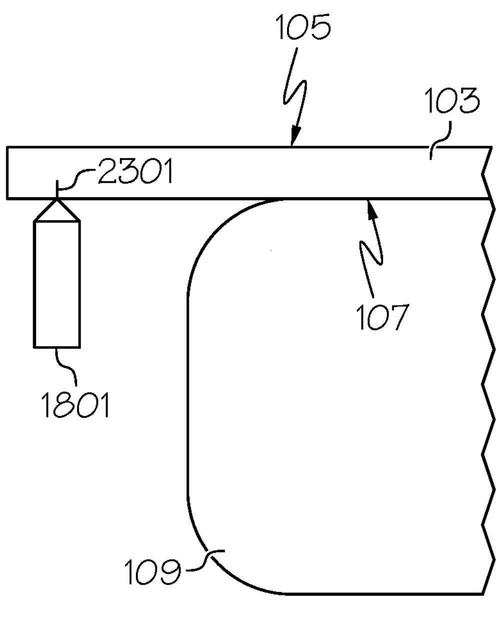

FIG. 23

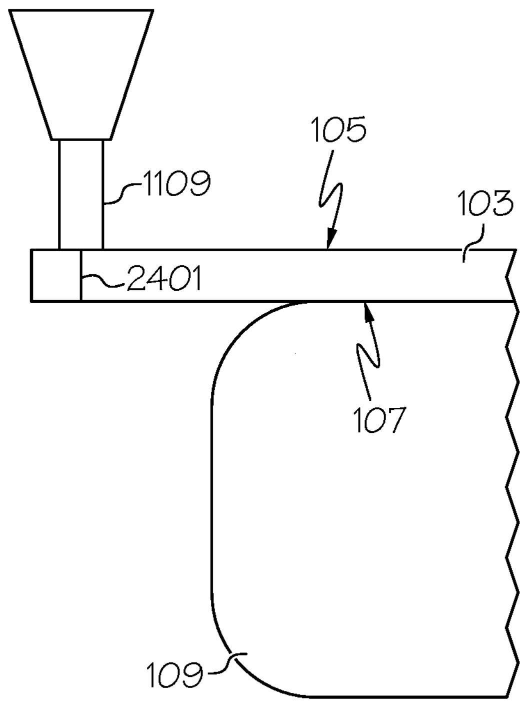

FIG. 24

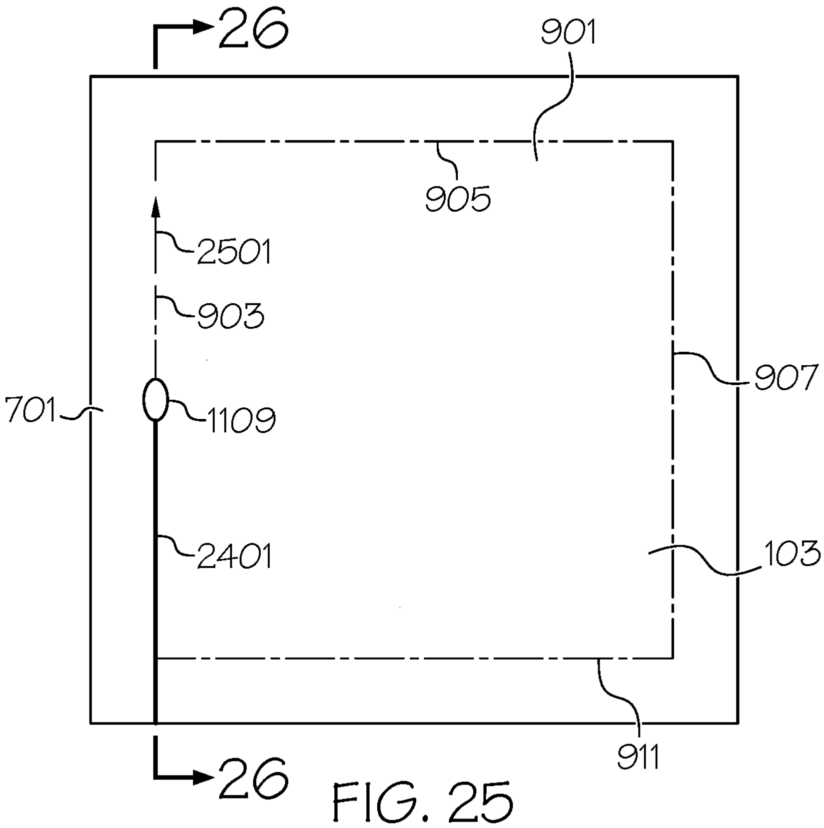
26
901
905
2501
903
907
701
1109
2401
103
911
26

FIG. 25

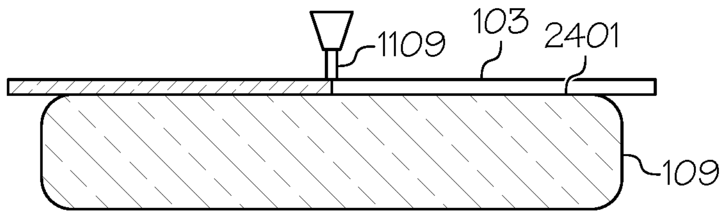
1109
103
2401
109

FIG. 26

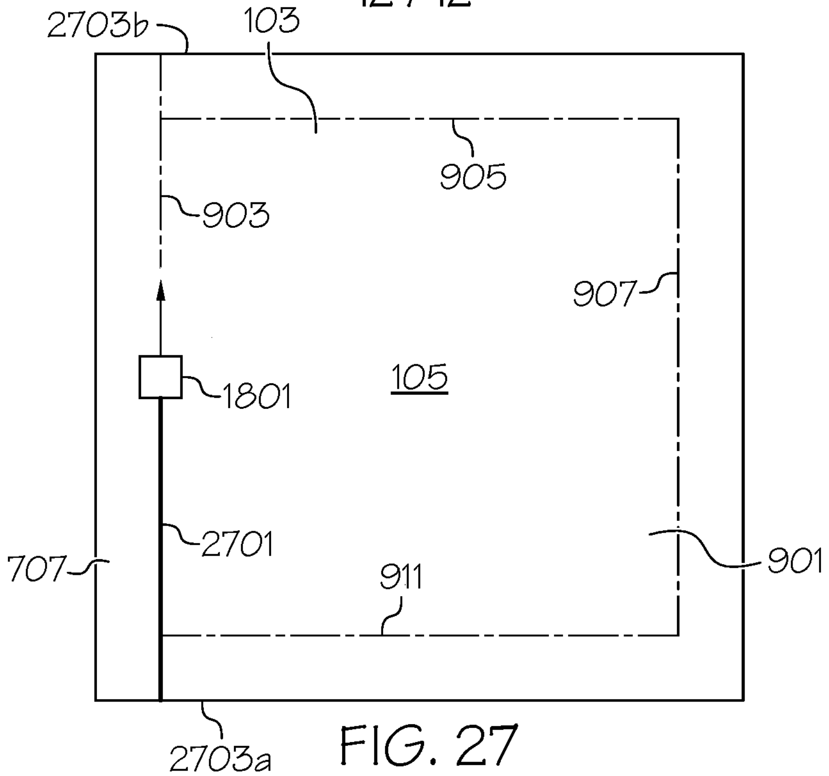

FIG. 27

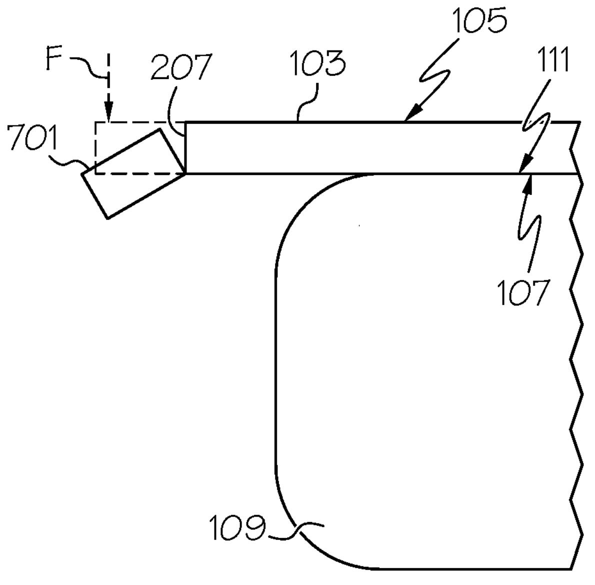

FIG. 28

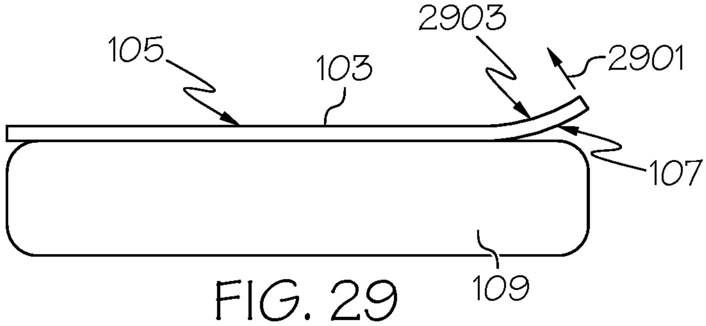

FIG. 29

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/012300

A. CLASSIFICATION OF SUBJECT MATTER
INV. B32B7/06 B32B17/06 C03B33/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B32B C03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/202030 A1 (KONDO SATOSHI [JP] ET AL) 9 August 2012 (2012-08-09) paragraph [0057] - paragraph [0059]; figures 4,5 paragraph [0068] - paragraph [0072] paragraph [0208] - paragraph [0210]; claims 1,7,10,15-17; example 2	1-3,14, 16-20

X	US 2012/080403 A1 (TOMAMOTO MASAHIRO [JP] ET AL) 5 April 2012 (2012-04-05)	21
A	paragraph [0050] - paragraph [0056] paragraph [0068] - paragraph [0073]; claims; figures 6(a),6(b) paragraph [0078] - paragraph [0079]	1-3,13, 15-20

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 April 2016	22/04/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Lindner, Thomas

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/012300

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	WO 2014/031374 A1 (CORNING INC [US]; DAWES STEVEN BRUCE [US]; GARNER SEAN MATTHEW [US]) 27 February 2014 (2014-02-27) paragraph [0047] - paragraph [0055]; claims; figures 1-5 paragraph [0074] -----	1-21
A	US 2010/212361 A1 (ABRAMOV ANATOLI ANATOLYEVICH [US] ET AL) 26 August 2010 (2010-08-26) claims; figures -----	4-12
A	US 2011/127242 A1 (LI XINGHUA [US]) 2 June 2011 (2011-06-02) claims; figures -----	4-12

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International application No
PCT/US2016/012300

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