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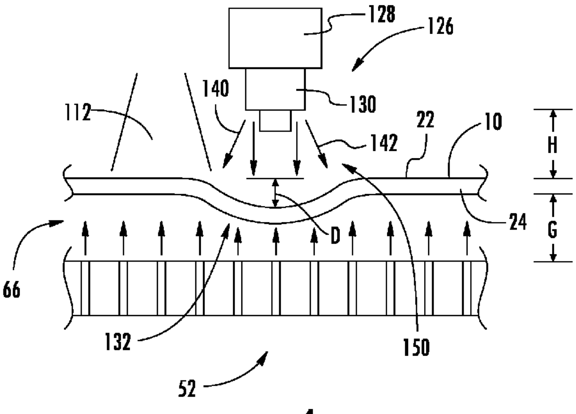

FIG. 4

(57) Abstract: A method for cutting a flexible glass substrate is provided. The method includes directing the flexible glass substrate to a flexible glass cutting apparatus including a laser. The flexible glass substrate includes a first broad surface and a second broad surface that extend laterally between a first edge and a second edge of the flexible glass substrate. A laser beam is directed from the laser onto a region of the flexible glass substrate. A crack is formed through the flexible glass substrate using the laser beam. A local mechanical deformation is formed in the flexible glass substrate using a stress-inducing assembly that includes a stress-inducing feature allowing the flexible glass substrate to deform locally. The crack is propagated along the flexible glass substrate using the laser beam and the local mechanical deformation.

WO 2016/011114 A1

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METHODS AND APPARATUS FOR CONTROLLED LASER CUTTING OF FLEXIBLE GLASS

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. 62/026258 filed on July 18, 2014, the content of which is relied upon and incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present invention relates to apparatuses and methods for controlled laser cutting of flexible glass.

BACKGROUND

[0003] Glass sheets have been used in the manufacture of display devices such as liquid crystal display (LCD) TVs, computer monitors and handheld devices. For example, in a modern LCD TV set, a piece of thin glass sheet with pristine surface quality is used as a substrate for thin-film-transistor (TFT) and other electronic devices, and another piece is used as a substrate for the color filter. Recently, thin glass sheets started to find use as cover sheets for the screens of handheld devices and TV sets as well.

[0004] The thin glass sheets may be made by using a fusion down-draw process, a float forming process, or other forming methods, from glass melt. Because these forming processes are frequently continuous on an industrial scale, as-formed glass ribbons immediately exiting the forming facility often need to be cut into multiple, continuous strips and/or discreet glass sheets before being shipped to device manufacturers. The cut glass sheets produced at the glass forming production lines often have sizes that can accommodate the manufacture of multiple devices on the same surface simultaneously. At a certain point of time, such large glass sheets need to be cut into smaller size of the final devices.

SUMMARY

[0005] The present concept involves laser cutting of a flexible glass substrate using mechanical deformation of the flexible glass substrate through the use of a carrier or other stress-inducing member having a stress-inducing feature to assist in propagating a flaw through the glass substrate. The mechanical deformation may be in the form of a depression/dimple or protuberance/hump that is formed by providing a stress-inducing feature that can be used to impart a tensile stress profile used to sever the flexible glass

substrate. The mechanical deformation may be in addition to any deformation caused by the laser beam, itself, which can stabilize crack propagation.

[0006] Cutting a moving glass substrate, or web, using a laser, for example a CO_2 laser, typically involves three steps:

1. Creation of small initiation defect on the glass surface by, for example, a diamond impregnated wheel or stylus in front of the laser beam;
2. Heating the glass surface by the laser beam along the desired cutting direction; and
3. Cooling down the laser heated surface locally to cause tensile forces on the surface to propagate the crack or partial vent starting from the initiation defect.

[0007] It has been discovered that creation of a local mechanical stress in the glass substrate and superimposed on the stress field generated by the laser beam can result in a more controlled crack propagation of the full depth cut ("full body cut") of the flexible glass substrate. For example, formation of a depression/dimple or protuberance/hump in the glass surface can enable tensioning of the glass and propagation of the crack.

[0008] The controlled flexible glass deformation can improve the precision and consistency of the laser cutting process of glass by placing the glass surface into tension, predisposing the flexible glass substrate to break along the course of the laser beam. Such localized flexible glass deformation can provide predominantly symmetrical and uniaxial stress field through the thickness of the flexible glass substrate, which promotes crack propagation in the direction perpendicular to the glass surface, minimizing edge plane change and twist hackle. It can also provide an advantage over "traditional" laser cutting methods by minimizing variations of the crack propagation velocity by isolating the tip of the crack from vibrations of the glass originated from different sources (bead chopper, edge lamination, inconsistency of air-bearing glass web support, incoming web shape etc.), outside the cutting area, and, thus, can enable overall robustness of the process and improved edge quality. This is particularly important when performing continuous laser cutting of thin, moving webs.

[0009] According to a first aspect, a method for cutting a flexible glass substrate, the method comprises:

directing the flexible glass substrate to a flexible glass cutting apparatus including a laser, the flexible glass substrate including a first broad surface and a second broad surface that extend laterally between a first edge and a second edge of the flexible glass substrate;

directing a laser beam from the laser onto a region of the flexible glass substrate;

forming a crack through the flexible glass substrate using the laser beam;

forming a local mechanical deformation in the flexible glass substrate using a stress-inducing assembly comprising a stress-inducing feature allowing the flexible glass substrate to deform locally; and

propagating the crack along the flexible glass substrate using the laser beam and the local mechanical deformation.

[0010] According to a second aspect, there is provided the method of aspect 1, further comprising forming an initiation defect in the flexible glass substrate between the first and second edges.

[0011] According to a third aspect, there is provided the method of aspect 1 or aspect 2, wherein the stress-inducing feature is a trough into which the flexible glass substrate deforms.

[0012] According to a fourth aspect, there is provided the method of aspect 3, wherein the local mechanical deformation is formed by directing a pressurized gas onto the flexible glass substrate thereby deforming the flexible glass substrate into the trough.

[0013] According to a fifth aspect, there is provided the method of any one of aspects 1-4, wherein the local mechanical deformation is at least partially formed in the region where the laser beam is directed.

[0014] According to a sixth aspect, there is provided the method of any one of aspects 1-5, wherein the local mechanical deformation is a depression having a depth of between about 0.1 mm and about 1 mm.

[0015] According to a seventh aspect, there is provided the method of any one of aspects 1-6, wherein an amount of tensile stress introduced by the local mechanical deformation in the flexible glass substrate is no greater than 50 percent of an amount of tensile stress introduced by the laser beam.

[0016] According to an eighth aspect, there is provided the method of any one of aspects 1-7, wherein the step of directing the flexible glass substrate to the flexible glass cutting apparatus includes floating the flexible glass substrate along a non-contact support member comprising an air bar, the stress-inducing assembly being connected to the air bar.

[0017] According to a ninth aspect, there is provided the method of aspect 8, wherein the stress-inducing assembly comprises a roller that is recessed in the air bar and configured to contact the flexible glass substrate during a cutting operation thereby maintaining spacing between the air bar and the flexible glass substrate.

[0018] According to an tenth aspect, there is provided the method of aspect 8 or aspect 9, wherein the stress-inducing assembly comprises multiple rollers, wherein a first roller contacts the flexible glass substrate at the first broad surface and a second roller contacts the flexible glass substrate at the second broad surface to apply the local mechanical deformation.

[0019] According to an eleventh aspect, a method for cutting a flexible glass substrate, the method comprising:

providing a flexible glass substrate and a carrier substrate, the flexible glass substrate and carrier substrate sized and configured to float using an air bearing provided by a non-contact support member, where the carrier substrate includes a stress-inducing feature allowing the flexible glass substrate to deform locally forming a local mechanical deformation;

directing a laser beam from a laser onto a region of the flexible glass substrate corresponding to the local mechanical deformation; and

propagating a crack along the flexible glass substrate using the laser beam and the local mechanical deformation.

[0020] According to a twelfth aspect, there is provided the apparatus of aspect 11, wherein the carrier substrate comprises at least one of a paper and release film.

[0021] According to a thirteenth aspect, there is provided the apparatus of aspect 11 or aspect 12, wherein the stress-inducing feature includes a channel formed through the carrier substrate.

[0022] According to a fourteenth aspect, there is provided the apparatus of aspect 13, further comprising moving the laser beam along the channel.

[0023] According to a fifteenth aspect, a glass processing apparatus for cutting a flexible glass substrate, the glass processing apparatus comprises:

a conveying path along which the flexible glass substrate may be conveyed through the glass processing apparatus;

a glass cutting apparatus for cutting the flexible glass substrate conveyed along the conveying path, the glass cutting apparatus comprising an optical delivery apparatus arranged and configured to direct a laser beam onto the flexible glass substrate conveyed along the conveying path for heating a region of the flexible glass substrate and introducing a first amount of tensile stress to the flexible glass substrate; and

a non-contact support member comprising a stress-inducing assembly comprising a stress-inducing feature allowing the flexible glass substrate to deform locally forming a local mechanical deformation introducing a second amount of tensile stress to the flexible substrate.

[0024] According to a sixteenth aspect, there is provided the apparatus of aspect 15, wherein the second amount of tensile stress is less than the first amount of tensile stress.

[0025] According to a seventeenth aspect, there is provided the apparatus of aspect 15 or aspect 16, further comprising a pressurized gas delivery device arranged and configured to form the local mechanical deformation in the flexible glass substrate at the stress-inducing feature.

[0026] According to an eighteenth aspect, there is provided the apparatus of any one of aspects 15-17, wherein the non-contact support member comprises an air bar, the stress-inducing assembly comprises a roller that is recessed in the air bar and configured to contact the flexible glass substrate during a cutting operation thereby maintaining spacing between the air bar and the flexible glass substrate.

[0027] According to a nineteenth aspect, there is provided the apparatus of any one of aspects 15-18, wherein the stress-inducing assembly comprises multiple rollers, wherein a first roller contacts the flexible glass substrate at a first broad surface and a second roller contacts the flexible glass substrate at a second, opposite broad surface to apply the local mechanical deformation.

[0028] According to a twentieth aspect, there is provided the apparatus of any one of aspects 15-19, wherein the stress-inducing feature is a trough into which the flexible glass substrate deforms, the local mechanical deformation is formed by directing a pressurized gas onto the flexible glass substrate thereby deforming the flexible glass substrate into the trough.

[0029] Additional features and advantages will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from the description or recognized by practicing the invention as exemplified in the written description and the appended drawings and as defined in the appended claims. It is to be understood that both the foregoing general description and the following detailed description are merely exemplary of the invention, and are intended to provide an overview or framework to understanding the nature and character of the invention as it is claimed.

[0030] The accompanying drawings are included to provide a further understanding of principles of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate one or more embodiment(s), and together with the description serve to explain, by way of example, principles and operation of the invention. It is to be understood that various features of the invention disclosed in this specification and in the drawings can be used in any and all combinations.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] FIG. 1 is a partial view of an embodiment of an apparatus for processing a flexible glass substrate;

[0032] FIG. 2 is a section view along line 2-2 of FIG. 1 illustrating an embodiment of a cutting support member with an upwardly extending convex support surface;

[0033] FIG. 3 illustrates a schematic view of an embodiment of an apparatus for processing a flexible glass substrate;

[0034] FIG. 4 is a schematic side view of an embodiment of a cutting apparatus including a nozzle and pressurized air forming a local depression in a flexible glass substrate;

[0035] FIG. 5 is a schematic top view of a flexible glass substrate having a local depression;

[0036] FIG. 6 is a bottom view of an embodiment of a nozzle;

[0037] FIG. 7 illustrates a top view of an embodiment of an air bar assembly including an embodiment of an air bar insert assembly;

[0038] FIG. 8 is a perspective view of an embodiment of an apparatus for processing a flexible glass substrate including the air bar assembly of FIG. 7;

[0039] FIG. 9 is a schematic front view of an embodiment of a roller for use with the air bar assembly of FIG. 7;

[0040] FIG. 10 is a another embodiment of an air bar insert assembly;

[0041] FIG. 11 illustrates another embodiment of a stress-inducing assembly;

[0042] FIG. 12 illustrates another embodiment of a stress-inducing assembly;

[0043] FIG. 13 illustrates another embodiment of a stress-inducing member including a stress-inducing feature;

[0044] FIG. 14 illustrates another embodiment of a stress-inducing member including a stress-inducing feature; and

[0045] FIGS. 15 and 16 illustrate another embodiment of a stress-inducing member including a stress-inducing feature.

DETAILED DESCRIPTION

[0046] Embodiments described herein generally relate to processing of flexible glass substrates and, more particularly, to cutting the flexible glass substrates, for example, into multiple flexible glass ribbons and/or into discrete flexible glass sheets of a variety of shapes and sizes. The embodiments described herein may also relate to trimming edges or other portions of the flexible glass substrates, for example, to remove thickened or beaded edge portions. As used herein, the term “substrate” may refer to any length of flexible glass such as sheets or a web fed continuously, for example, from a roll or forming process, sometimes referred to as a ribbon. Cutting of the flexible glass substrate is achieved using a laser beam assisted by a local mechanical deformation (e.g., a depression or protuberance). The local mechanical deformation, in some embodiments, may be considered “floating” in that it moves along a surface of the flexible glass substrate during a cutting process. In other embodiments, the local mechanical deformation may be stationary. The local mechanical deformation creates a tension field in the flexible glass substrate that can be used along with a tension field supplied by localized heating, e.g., using a laser, together with localized cooling, e.g., using a fluid jet, to propagate a crack through a thickness of the flexible glass substrate perpendicular to broad surfaces of the flexible glass substrate.

[0047] Referring to FIG. 1, a flexible glass substrate 10 is illustrated being conveyed through a glass processing apparatus 12, only a portion of which is illustrated by FIG. 1. The flexible glass substrate 10 may be conveyed in a continuous fashion from a glass substrate source 14 through the glass processing apparatus 12. The flexible glass substrate 10 includes a pair of opposed first and second edges 16 and 18 that extend along a length of the flexible glass substrate 10 and a central portion 20 that spans between the first and second edges 16 and 18. In some embodiments, the first and second edges 16 and 18 may be covered in an adhesive tape 25 that is used to protect and shield the first and second edges 16 and 18 from contact. The tape 25 may be applied to one or both of the first and second edges 16 and 18 as the flexible glass substrate 10 moves through the apparatus 12. In other embodiments, no adhesive tape 25 may be used to cover the first and second edges 16 and 18. A first broad surface 22 and an opposite, second broad surface 24 also spans between the first and second edges 16 and 18, forming part of the central portion 20.

[0048] In embodiments where the flexible glass substrate 10 is formed using a down draw fusion process, which is shown in part in FIG. 3, the first and second edges 16 and 18 may include beads 26 and 28 with a thickness T_1 that is greater than a thickness T_2 within the central portion 20. The central portion 20 may be “ultra-thin” having a thickness T_2 of about 0.3 mm or less including but not limited to thicknesses of, for example, about 0.01-0.05 mm, about 0.05-0.1 mm, about 0.1-0.15 mm and about 0.15-0.3 mm, 0.3, 0.29, 0.28, 0.27, 0.26, 0.25, 0.24, 0.23, 0.22, 0.21, 0.2, 0.19, 0.18, 0.17, 0.16, 0.15, 0.14, 0.13, 0.12, 0.11, 0.1, 0.09, 0.08, 0.07, 0.06, or 0.05 mm although flexible glass substrates 10 with other thicknesses may be formed in other examples.

[0049] The flexible glass substrate 10 is conveyed through the apparatus 12 using a conveyor system 30. Lateral guides 32 and 34 may be provided to orient the flexible glass substrate 10 in the correct lateral position relative to the machine or travel direction 36 of the flexible glass substrate 10. For example, as schematically shown, the lateral guides 32 and 34 may include rollers 38 that engage the first and second edges 16 and 18. Opposed forces 40 and 42 may be applied to the first and second edges 16 and 18 using the later guides 32 and 34 that help to shift and align the flexible glass substrate 10 in the desired lateral orientation in the travel direction 36.

[0050] As further illustrated, the lateral guides 32 and 34 can engage the first and second edges 16 and 18 on the tape 25 without engaging the central portion 20 of the flexible glass substrate 10. As such, the pristine or quality surfaces of the opposed first and second broad surfaces 22 and 24 of the central portion 20 of the flexible glass substrate 10 can be maintained while avoiding undesired scribing, scratching, or other surface contamination that might otherwise occur if the lateral guides 32 and 34 were to engage either of the first and second broad surfaces 22 and 24 of the central portion 20. Moreover, the lateral guides 32 and 34 may engage the flexible glass substrate 10 as it is being bent about an axis 46 transverse to the travel direction 36 of the flexible glass substrate 10. Bending the flexible glass substrate 10 can increase the rigidity of the glass substrate 10 throughout the bend. As such, the lateral guides 32 and 34 can engage the glass substrate 10 in bent and substantially planar conditions. The forces 40 and 42 applied by the lateral guides 32 and 34 are less likely to buckle or otherwise disturb the stability of the glass substrate profile when laterally aligning as the flexible glass substrate 10 when in a bent condition.

[0051] The apparatus 12 can further include a cutting zone 50 downstream from the axis 46. In one example, the apparatus 12 may include a cutting support member 52 configured to bend the flexible glass substrate 10 in the cutting zone 50 to provide a bent target segment 54 with a bent orientation. Bending the target segment 54 within the cutting zone 50 can help stabilize the flexible glass substrate 10 during the cutting procedure. Such stabilization can help inhibit buckling or disturbing the flexible glass substrate profile during the procedure of cutting the flexible glass substrate 10. In other embodiments, the cutting support member 52 may not bend the flexible glass substrate 10, instead providing and supporting the flexible glass substrate 10 in a substantially planar orientation.

[0052] The cutting support member 52 can comprise a non-contact cutting support member 52 designed to support the glass substrate 10 without touching the first and second broad surfaces 22 and 24 of the flexible glass substrate 10. For example, referring to FIG. 2, the non-contact cutting support member 52 can comprise one or more curved air bars configured to provide a cushion of air to space between the flexible glass substrate 10 and the cutting support member 52 to prevent the central portion 20 of the flexible glass substrate 10 from contacting the cutting support member 52. The space can also facilitate the formation of a local mechanical deformation in the flexible glass substrate 10 during a cutting operation, as will be described in greater detail below.

[0053] Referring to FIG. 2, the cutting support member 52 can be provided with a plurality of passages 58 configured to provide positive pressure ports 64 such that an air stream 62 can be forced through the positive pressure ports 64 toward the bent target segment 54 to create an air cushion 66 for non-contact support of the bent target segment 54. Optionally, the plurality of passages 58 can include negative pressure ports 68 such that an air stream 70 can be drawn away from the bent target segment 54 to create a suction to partially counteract the force from the air cushion 66 created by the positive pressure ports 64. A combination of positive and negative pressure ports can help stabilize the bent target segment 54 throughout the cutting procedure. Indeed, the positive pressure ports 64 can help maintain a desired air cushion 66 height between the central portion 20 of the flexible glass substrate 10 and the cutting support member 52. At the same time, the negative pressure ports 68 can help pull the flexible glass substrate 10 toward the cutting support member 52 to prevent the flexible glass substrate 10 from undulating or having portions of the bent target segment 54 from floating away from other portions of the target segment 54 when traversing over the cutting support member 52 in the travel direction 36.

[0054] Providing the bent target segment 54 in the cutting zone 50 can also increase the rigidity of the flexible glass substrate 10 throughout the cutting zone 50. As such, as shown in FIG. 1, optional lateral guides 70, 72 can engage the flexible glass substrate 10 in a bent condition as the flexible glass substrate 10 passes over the cutting support member 52 within the cutting zone 50. Forces 74 and 76 applied by the lateral guides 70 and 72 are therefore less likely to buckle or otherwise disturb the stability of the glass substrate profile when laterally aligning as the flexible glass substrate 10 passes over the cutting support member 52. The optional lateral guides 70 and 72 can therefore be provided to fine tune the bent target segment 54 at the proper lateral orientation along a direction of the axis 46 transverse to the travel direction 36 of the flexible glass substrate 10.

[0055] As set forth above, providing the bent target segment 54 in a bent orientation within the cutting zone 50 can help stabilize the flexible glass substrate 10 during the cutting procedure. Such stabilization can help prevent buckling or disturbing the glass substrate profile during the procedure of separating at least one of the first and second edges 16 and 18. Moreover, the bent orientation of the bent target segment 54 can increase the rigidity of the bent target segment 54 to allow optional fine tune adjustment of the lateral orientation of the bent target segment 54. As such, the flexible glass substrate 10 can be effectively stabilized and properly laterally oriented without contacting the first and second broad surfaces 22 and 24 of the central portion 20 during the procedure of separating at least one of the first and second edges 16 and 18.

[0056] Increased stabilization and rigidity of the bent target segment 54 of the flexible glass substrate 10 can be achieved by bending the target segment 54 to include an upwardly convex surface and/or an upwardly concave surface along a direction of the axis 46. For example, as shown in FIG. 2, the bent target segment 54 includes a bent orientation with an upwardly facing convex surface 80. Examples of the disclosure can involve supporting the bent target segment 54 with an upwardly facing convex support surface 82 of the cutting support member 52, such as the illustrated air bar. Providing the cutting support member 52 with an upwardly facing convex support surface 82 can likewise bend the flexible glass substrate 10 in the cutting zone 50 to achieve the illustrated bent orientation.

[0057] The apparatus 12 can further include a flexible glass cutting apparatus 100 configured to sever portions 101 and 103 of the flexible glass substrate 10 from one another. In one example, as shown in FIG. 3, the glass cutting apparatus 100 can include an optical delivery apparatus 102 for irradiating and therefore heating a portion of the upwardly facing surface of the bent target segment 54. In one example, optical delivery apparatus 102 can comprise a cutting device such as the illustrated laser 104 although other radiation sources may be provided in further examples. The optical delivery apparatus 102 can further include a circular polarizer 106, a beam expander 108, and a beam shaping apparatus 110.

[0058] The optical delivery apparatus 102 may further comprise optical elements for redirecting the beam of radiation (e.g., laser beam 112) from the radiation source (e.g., laser 104), such as mirrors 114, 116 and 118. The radiation source can comprise the illustrated laser 104 configured to emit a laser beam having a wavelength and a power suitable for heating the flexible glass substrate 10 at a location where the beam is incident on the flexible glass substrate 10. In one embodiment, laser 104 can comprise a CO_2 laser although other laser types may be used in further examples.

[0059] The laser 104 may be configured to initially emit the laser beam 112 with a substantially circular cross section. The optical delivery apparatus 102 is operable to transform laser beam 112 such that the beam 112 has a significantly elongated shape when incident on glass substrate 10. As shown in FIG. 1, the elongated shape can produce an elongated radiation zone 120 that may include the illustrated elliptical footprint although other configurations may be provided in further examples. The elliptical foot print can be positioned on the upwardly facing convex surface of the bent target segment.

[0060] The boundary of the elliptical footprint can be determined as the point at which the beam intensity has been reduced to $1/e^2$ of its peak value. The laser beam 112 passes through circular polarizer 106 and is then expanded by passing through beam expander 108. The expanded laser beam 112 then passes through beam shaping apparatus 110 to form a beam producing the elliptical footprint on a surface of the bent target segment 54. The beam shaping apparatus 110 may, for example, comprise one or more cylindrical lenses. However, it should be understood that any optical elements capable of shaping the beam emitted by laser 104 to produce an elliptical footprint on the bent target segment 54 may be used.

[0061] The elliptical footprint can include a major axis that is substantially longer than a minor axis. In some embodiments, for example, the major axis is at least about ten times longer than minor axis. However, the length and width of the elongated radiation zone are dependent upon the desired separating speed, desired initial crack size, thickness of the glass substrate, laser power, etc., and the length and width of the radiation zone may be varied as needed.

[0062] As further shown in FIGS. 1 and 3, the exemplary glass cutting apparatus 100 may also include a defect initiation device 122. The defect initiation device 122 can initiate or form a defect on one or both of the first and second broad surfaces 22 and 24 at or near the start of a desired cutting line. In some embodiments, a continuous initiation defect 124 (e.g., a scribe line across an entire or only a portion of a length or width of the flexible glass substrate) may be formed, or one or more discrete initiation defects of limited length may be formed where only one or more portions, for example, an edge (e.g., a leading edge) and/or location(s) spaced from the edge of the flexible glass substrate 124 is scribed or nicked. In some instances, a continuous initiation defect 124 may be desired because the tensile stresses to propagate the defect may be lower compared to use of multiple discrete defects only. In some embodiments, the initiation defect may be continuous only until separation of the flexible glass begins. Various methods and tools can be used to form the initiation defect. For example, a scribing wheel, a contacting pin, or other mechanical device having a hard contacting tip made of, e.g., SiC, diamond, and the like, can be used to form the defect such as a scribe line on either or both the first and second broad surfaces 22 and 24 of the flexible glass substrate 10. Because the overall thickness of the flexible glass substrate 10 may be at most 300 μm, in some instances, a continuous initiation defect through at least a portion of a thickness of the flexible glass substrate 10 can be relatively easily and conveniently formed in the scribing process. In some embodiments, the initiation defect can be created by laser ablation, melting, or thermal shock.

[0063] The glass cutting apparatus 100 further includes a pressurized gas delivery device 126. Although “gas” is used herein, other suitable fluids (including liquids) may be used instead. FIG. 4 illustrates a more detailed view of the gas delivery device 126, which includes a compressor or other pressurized gas source 128 that is fluidly connected to a nozzle 130. The nozzle 130 may be located at a downstream location relative to the defect initiation device 122 and laser 104, so that the initiation defect 124 is formed and the flexible glass substrate 10 is heated before reaching the nozzle 130.

[0064] As indicted above, the non-contact cutting support member 52 can support the glass substrate 10 without touching the first and second broad surfaces 22 and 24 of the flexible glass substrate 10 using air cushion 66. In some embodiments, the second broad surface 24 of the flexible glass substrate 10 may be maintained a height G of at least about 0.3 mm from the non-contact cutting support member 52, such as in the range of about 0.3 mm to about 1.5 mm, such as about 0.7 mm to about 1.1 mm. Maintaining a height G below the nozzle 130 allows for formation of a dimple or local depression 132 in the flexible glass substrate 10.

[0065] Referring also to FIG. 5, the initiation defect 124 is formed as a continuous scribe line extending in the machine direction in the first broad surface 22 of the flexible glass substrate 10 before reaching the laser beam 112. As can be seen, the laser beam 112 may be somewhat elongated in shape, having the long axis extending in the machine direction and the short axis extending in the cross-machine direction. The laser beam 112 is used to heat the flexible glass substrate 10 locally from an initial temperature to a higher temperature. The initial temperature of the flexible glass substrate can depend on the specific process that the flexible glass substrate 10 is subjected to. For example, in cases where the flexible glass substrate is formed at the bottom of a draw of a fusion down-draw or slot down-draw process, or a flexible glass substrate formed from a float process immediately after bath, the initial temperature of the flexible glass substrate 10 may be relatively high, such as about 400 °C more or less. A lower initial temperature for the flexible glass substrate 10 may be desirable before heating with the laser beam 112, such as no more than about 300 °C, such as no more than about 200 °C, such as no more than about 100 °C, such as no more than about 50 °C, such as no more than about 30 °C, such as between about 15 °C and about 30 °C. In some embodiments, the flexible glass substrate 10 may be heated locally at the initiation defect 124 at least about 100 °C from the initial temperature, such as at least about 200 °C, such as at least about 300 °C, such as at least about 400 °C.

[0066] The nozzle 130 (FIG. 4) directs pressurized gas (e.g., air) onto the first surface 22 of the flexible glass substrate 10, which can provide surface cooling and formation of the local depression 132, both of which can be used to introduce tensile stresses in the flexible glass substrate 10, wherein the tensile stresses may be present at the initiation defect 124 as it passes by the nozzle 130 as the flexible glass substrate 10 moves relative thereto. The nozzle 130 may be a divergent flow-type nozzle where at least a portion of the pressurized gas is directed outwardly away from a central axis C of the nozzle 130 (see arrows 140 and 142). Referring briefly to FIG. 6, the nozzle 130 may include an annular air flow passageway 144 and a solid core 146 extending therethrough. Such an arrangement can provide the divergent air flow pattern depicted by FIG. 4 and circular local depression 132 of FIG. 5. The use of a stream 150 of pressurized gas to form the local depression 132 in the flexible glass substrate 10 at the initiation defect 124 can produce a stable, directed cut in the flexible glass substrate 10 that is less sensitive to downstream handling vibrations. The stream 150 of pressurized gas creates tensile stresses by cooling and by distending the first and second broad surfaces 22 and 24 of the flexible glass substrate 10. These surface tensile stresses facilitate crack propagation, even for relatively low thermal expansion glasses.

[0067] During cutting, pressure in the nozzle 130 may be maintained at a pressure of between about 20 psi and about 80 psi, such as between about 40 psi and about 65 psi. The nozzle 130 may be maintained at a height H, which can depend on the pressure and desired depth of the local depression 132. Depth D of the local depression 132 may be controlled by the pressure in the nozzle 130, which is counter balanced by the air flow from the non-contact cutting support member 52. The local depression 132 remains stationary, floating or travelling along the length of the flexible glass substrate 10 as the flexible glass substrate 10 moves by the nozzle 130. In some embodiments, the depth D of the local depression 132 may be between about 0.1 mm to about 1 mm. The depth D of the local depression 132 may be controlled by varying or controlling pressure in the nozzle 130, width or diameter of the local depression 132 (e.g., between about 3 mm and about 25 mm) and pressure in the non-contact cutting support member 52. As can be seen, the local depression 132 may intersect at least a portion of the laser beam 112. In other embodiments, the local depression 132 may be located downstream or at least a portion of the local depression 132 may be located downstream of the laser beam 112. In some embodiments, when the cutting process is initiated by the initial creation of an initiation defect 124, the pressure in the nozzle 130 may be set at 0 psi to minimize the possibility of lateral cracking on the flexible glass substrate 10 at the initiation point. After the initiation defect 124 is created and heating using the laser beam 112 begins, the pressure in the nozzle 130 may be increased to create the local depression 132.

[0068] While the non-contact cutting support member 52 can support the glass substrate 10 without touching the first and second broad surfaces 22 and 24 of the flexible glass substrate 10 using air cushion 66, application of the laser beam 122 and the pressurized gas onto the first surface 22 tends to move the flexible glass substrate 10 toward the cutting support member 52. Such an occurrence can result in replacement of the air bars and/or contamination of the second broad surface 24 and edges (e.g., with aluminum).

[0069] Referring to FIG. 7, a stress-inducing assembly 200 is provided that can both aid in creating the local mechanical deformation using the pressurized air, and also maintain a controlled distance of the flexible glass substrate 10 from the non-contact cutting support member 52. In the illustrated embodiment, the stress-inducing assembly 200 is in the form of an air bar insert assembly 202 of an air bar assembly 204. The air bar assembly 204 includes an air bar 206 and the air bar insert assembly 202 that is connected to the air bar 206 at a touchdown location 218. The touchdown location 218 can correspond to any location where the flexible glass substrate 10 may tend to contact the air bar 206, particularly at the cutting zone 50 where pressure is applied to the flexible glass substrate 10 in a direction toward the non-contact cutting support member 52.

[0070] The air bar insert assembly 204 includes a connecting plate 210 that can be connected to the air bar 206, e.g., by fasteners or any other suitable connection. In some embodiments, the connecting plate 210 may coextend over a surface 212 of the air bar 206 having the plurality of passageways 58 (FIG. 2) extending therethrough. In these embodiments, the connecting plate 210 may also have a plurality of passageways 214 over its surface 218, where the passageways 214 of the connecting plate 210 are capable of communicating with the passageways 58 of the air bar 206 for operation like shown and described with reference to FIG. 2. A stress-inducing member in the form of a roller 220 may be connected to the connecting plate 210 of the air bar insert assembly 204. The roller 220 may be located within an opening 222 in the surfaces 212 and 218, such that the roller 220 is recessed within the opening 222.

[0071] Referring to FIG. 8, a non-contact cutting support member 230 is illustrated that is similar to the non-contact support member 52 of FIG. 2 that includes the air bar 206 and air bar insert assembly 204. The flexible glass cutting apparatus 100 including laser 104 and nozzle 130 is also illustrated. As can be seen, the roller 220 has an outer diameter that allows a portion of the roller 220 to extend upwardly beyond the surfaces 212 and 218 of the air bar

206 and connecting plate 210 a distance of at least about 0.3 mm, such as in the range of about 0.3 mm to about 1.5 mm, such as about 0.7 mm to about 1.1 mm. Such an arrangement can maintain the spacing or height G of the flexible glass substrate 10 from the non-contact support member 52 to be maintained, even where the laser beam 112 and pressurized gas apply a force against the flexible glass substrate 10 in a direction toward the non-contact support member 230.

[0072] Referring also to FIG. 9, the roller 220 is illustrated in isolation and includes sides 226 and 228 and an outer periphery 230 that extends between the sides 226 and 228 forming a rolling contact surface. A stress-inducing feature, such as a trough 232 is provided in the outer periphery 230 of reduced diameter, providing a recess into which the flexible glass substrate 10 may enter as shown, while being supported at the outer periphery 230 adjacent the trough 232. The trough 232 may be recessed below the outer periphery a distance of at least about 0.3 mm, such as in the range of about 0.3 mm to about 1.5 mm, such as about 0.7 mm to about 1.1 mm to facilitate formation of the local mechanical depression. The roller may be formed of or coated with any material suitable for contacting glass (e.g., anodized aluminum) while allowing the flexible glass substrate 10 to freely move in the conveying direction under rolling friction. While a rolling trough is depicted, a stationary trough may be used, such as a bar or plate including a trough placed above or below the flexible glass substrate 10.

[0073] Referring to FIG. 10, another embodiment of an air bar insert assembly 240 includes a connecting plate 242 that can be connected to the air bar 206, as described above. In this embodiment, the air bar assembly 240 includes a pair of stress-inducing members in the form of rollers 242 and 246. The roller 242 may have an arrangement similar to the roller 220 of FIG. 9. In this embodiment, however, roller 246 also includes a stress-inducing feature, such as a trough 248 that is aligned with trough 250 of roller 242. In other embodiments, the stress-inducing feature may be a protuberance or a continuous rib about the outer periphery of the roller. The rollers 242 and 246 each provide a compressive force against the flexible glass substrate 10 that controls the stress path provided by the laser beam. This embodiment may be used to eliminate use of pressurized gas to propagate the crack using only the laser-induced tensile stress profile. The rollers 242 and 246 may have a distance between them or nip less than the thickness of the flexible glass substrate 10. In some embodiments, the nip may have a fixed or variable width. For example, the roller 246 may be capable of movement away from roller 242 and be biased toward the roller 242, e.g., using a spring.

[0074] Referring to FIGS. 11 and 12, in other embodiments, multiple rollers may be used to provide the local mechanical stress (e.g., without gas pressure). Referring to FIG. 11, tension may be provided to the glass surface 24 with one roller 250 contacting glass surface 22 and two adjacent rollers 252 and 254 contacting glass surface 24. FIG. 12 illustrates tension provided to the glass surface 22 with one roller 256 contacting glass surface 24 and two adjacent rollers 258 and 260 contacting glass surface 22.

[0075] While the above processes and apparatus may be particularly, though not exclusively, useful in cutting long flexible glass substrates, such as in a roll-to-roll or glass forming process, other processes and apparatus may be particularly useful for cutting shorter sheet-form flexible glass substrates. For example, referring to FIGS. 13 and 14, a substrate stack 300 includes a carrier substrate 302 and a flexible glass substrate 304. The carrier substrate 306 has a glass support surface 308, an opposite support surface 310 and a periphery 312. The flexible glass substrate 314 has a first broad surface 316, an opposite, second broad surface 318 and a periphery 320.

[0076] The carrier substrate 306 is machined or otherwise formed to include a stress-inducing feature. In the embodiment of FIG. 13, the stress-inducing feature is in the form of a recess or trough 322. In the embodiment of FIG. 14, the stress-inducing feature is in the form of a protuberance or hump 324. Using air pressure applied to surfaces 316 or applying a vacuum against surfaces 318 (e.g., through the carrier substrate 306) can result in a slight concave (FIG. 13) or convex (FIG. 14) flexible glass shape at the location where the stress-inducing features are located. When a suitable magnitude of mechanical stress is generated by flexible glass deformation and is superimposed to the laser generated stress field, a consistently higher tensile stress can be maintained on either the top (FIG. 14) or bottom (FIG. 13) of the flexible glass substrate 304 in the fracture plane desired. This constant tensile stress can maintain crack propagation at the desired surface, irrespective of potential stress field perturbation during the cutting process.

[0077] In some embodiments, the amount of tensile stress on the glass surface 316, 318 is no greater than 50 percent of the laser generated stress field, such as no greater than 40 percent, such as no greater than 30 percent, such as no greater than 20 percent, such as no greater than 10 percent. As one illustrated example, if tensile stress to propagate a crack through the flexible glass substrate of 0.1 mm thickness is on the order of about 60 MPa, the amount of applied mechanical stress may be no greater than about 30 MPa, such as no greater than about 15 MPa. The amount of bending (bend radius) can be estimated by:

$$\sigma_{max} = 1.198[^{Et}/_{(D - t)}],$$

where E denotes Young's modulus of glass, t denotes thickness of the flexible glass substrate and D is twice the bend radius R with R given by

$$R = \frac{1.198Et + \sigma_{max}t}{2\sigma_{max}}$$

.

In this example, with the flexible glass substrate 10 having a Young's modulus of 72 GPa, a maximum bend radius of 144 mm applies less than 30 MPa mechanical tensile stress to retain the laser generated stress as the principle guiding stress for a cutting operation. One or more of carrier shapes, pneumatic pressure and/or dimple formation, such as through use of pressurized gas or liquid can be used. As one example a porous graphite, porous metal or porous ceramic may be used as a carrier. The carrier substrate may be formed to allow a vacuum to be applied to the flexible glass surface.

[0078] Referring to FIGS. 15 and 16, the above described applied mechanical tensile stresses may be used in a variety of contexts, such as on a float table 350 to laser cut a flexible glass substrate 352 carried on a floating carrier substrate 354. In this embodiment, the flexible glass substrate 352 and carrier substrate 354 are sized and configured to float above the float table 350. In order to focus the tensile stresses to controllably propagate a continuous crack, a channel 356 may be provided, which allows formation of a slight concave portion 358 in the flexible glass substrate 352 along the channel 356 due to the absence of the floating carrier substrate 354. In this example, the laser may move, directing the laser beam along the channel 356, while the flexible glass substrate 352 and the floating carrier substrate 354 remain stationary. Any suitable floating carrier substrate material may be used, such as clean room paper or a silicone release films (which may releasably adhere to the flexible glass substrate 22), such as BOPP, OPP, PP, HDPE, MDPE, LDPE, PE, PET and PMMA films. Further, any suitable patterns may be used for the channel of the carrier substrate, such as any regular or irregular shapes, square and rounded corners.

[0079] Alternatively, the table 350 may be a suction table, or a pressure/vacuum table, wherein instead of floating the flexible glass substrate 352 during the laser cutting operation, the flexible glass substrate is floated into position (with the table blowing air to support the glass substrate and/or carrier substrate) and then sucked down toward the table 350 with the carrier substrate 354 between the table and the glass substrate. In this situation, during laser cutting, the flexible glass substrate 352 is sucked down into the channel 356 forming a concave region which focuses the mechanical tensile stress to controllably propagate a continuous crack. As an alternative of the manner of positioning the glass on the table, the carrier substrate and glass may simply be positioned onto the table with no fluid being emitted from the table, and then suction used to hold the glass substrate and carrier substrate in position during laser cutting.

[0080] One or more of the above methods and apparatus can facilitate laser cutting of a flexible glass substrate using mechanical deformation of the flexible glass substrate through the use of a carrier or other stress-inducing member having a stress-inducing feature to assist in propagating a flaw through the glass substrate. In some embodiments, consistent process separation of flexible glass substrate is facilitated, which can create a larger process window delivering increased productivity. Increased precision along cutting lines and the ability to control crack leading surface can reduce potential strength limiting impacts and increase edge strength by reducing the frequency of low end breaks. Thermal contact with underlying carriers along the cut line can be minimized, thereby reducing thermal contact variations and improving cutting stability.

[0081] In the previous detailed description, for purposes of explanation and not limitation, example embodiments disclosing specific details are set forth to provide a thorough understanding of various principles of the present invention. However, it will be apparent to one having ordinary skill in the art, having had the benefit of the present disclosure, that the present invention may be practiced in other embodiments that depart from the specific details disclosed herein. Moreover, descriptions of well-known devices, methods and materials may be omitted so as not to obscure the description of various principles of the present invention. Finally, wherever applicable, like reference numerals refer to like elements.

[0082] For example, although a depression was described above as the local mechanical deformation, a raised area may (for example, in the shape of a dome extending outwardly and upwardly from the surface 22, as direction is shown in the figures) be used instead. Also, although the nozzle and the laser beam were described as acting on the same surface of the glass, they may instead act on opposite surfaces of the glass and the same stress-inducing effect can be achieved. Further, although the local mechanical deformation is shown as a circular, more generally, an oval shape may be used. Other devices (other than gas pressure and nozzles) may be used to form a local deformation in the flexible glass. For example, rollers, or other devices contacting the flexible glass may be used.

[0083] Ranges can be expressed herein as from "about" one particular value, and/or to "about" another particular value. When such a range is expressed, another embodiment includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent "about," it will be understood that the particular value forms another embodiment. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

[0084] Directional terms as used herein - for example up, down, right, left, front, back, top, bottom - are made only with reference to the figures as drawn and are not intended to imply absolute orientation.

[0085] Unless otherwise expressly stated, it is in no way intended that any method set forth herein be construed as requiring that its steps be performed in a specific order. Accordingly, where a method claim does not actually recite an order to be followed by its steps or it is not otherwise specifically stated in the claims or descriptions that the steps are to be limited to a specific order, it is no way intended that an order be inferred, in any respect. This holds for any possible non-express basis for interpretation, including: matters of logic with respect to arrangement of steps or operational flow; plain meaning derived from grammatical organization or punctuation; the number or type of embodiments described in the specification.

[0086] As used herein, the singular forms "a," "an" and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to a “component” includes aspects having two or more such components, unless the context clearly indicates otherwise.

[0087] It should be emphasized that the above-described embodiments of the present invention, particularly any “preferred” embodiments, are merely possible examples of implementations, merely set forth for a clear understanding of various principles of the invention. Many variations and modifications may be made to the above-described embodiments of the invention without departing substantially from the spirit and various principles of the invention. All such modifications and variations are intended to be included herein within the scope of this disclosure and the following claims.

What is Claimed:

1. A method for cutting a flexible glass substrate, the method comprising:

directing the flexible glass substrate to a flexible glass cutting apparatus including a laser, the flexible glass substrate including a first broad surface and a second broad surface that extend laterally between a first edge and a second edge of the flexible glass substrate;

directing a laser beam from the laser onto a region of the flexible glass substrate;

forming a crack through the flexible glass substrate using the laser beam;

forming a local mechanical deformation in the flexible glass substrate using a stress-inducing assembly comprising a stress-inducing feature allowing the flexible glass substrate to deform locally; and

propagating the crack along the flexible glass substrate using the laser beam and the local mechanical deformation.

2. The method of claim 1 further comprising forming an initiation defect in the flexible glass substrate between the first and second edges.

3. The method of claim 1 or claim 2, wherein the stress-inducing feature is a trough into which the flexible glass substrate deforms.

4. The method of claim 3, wherein the local mechanical deformation is formed by directing a pressurized gas onto the flexible glass substrate thereby deforming the flexible glass substrate into the trough.

5. The method of any one of claims 1-4, wherein the local mechanical deformation is at least partially formed in the region where the laser beam is directed.

6. The method of any one of claims 1-5, wherein the local mechanical deformation is a depression having a depth of between about 0.1 mm and about 1 mm.

7. The method of any one of claims 1-6, wherein an amount of tensile stress introduced by the local mechanical deformation in the flexible glass substrate is no greater than 50 percent of an amount of tensile stress introduced by the laser beam.

8. The method of any one of claims 1, 2, or 5-7, wherein the step of directing the flexible glass substrate to the flexible glass cutting apparatus includes floating the flexible glass substrate along a non-contact support member comprising an air bar, the stress-inducing assembly being connected to the air bar.

9. The method of claim 8, wherein the stress-inducing assembly comprises a roller that is recessed in the air bar and configured to contact the flexible glass substrate during a cutting operation thereby maintaining spacing between the air bar and the flexible glass substrate.

10. The method of claim 8, wherein the stress-inducing assembly comprises multiple rollers, wherein a first roller contacts the flexible glass substrate at the first broad surface and

a second roller contacts the flexible glass substrate at the second broad surface to apply the local mechanical deformation.

11. A method for cutting a flexible glass substrate, the method comprising:

providing a flexible glass substrate and a carrier substrate, the flexible glass substrate and carrier substrate sized and configured to float using an air bearing provided by a non-contact support member, where the carrier substrate includes a stress-inducing feature allowing the flexible glass substrate to deform locally forming a local mechanical deformation;

directing a laser beam from a laser onto a region of the flexible glass substrate corresponding to the local mechanical deformation; and

propagating a crack along the flexible glass substrate using the laser beam and the local mechanical deformation.

12. The method of claim 11, wherein the carrier substrate comprises at least one of a paper and release film.

13. The method of claim 11 or claim 12, wherein the stress-inducing feature includes a channel formed through the carrier substrate.

14. The method of claim 13 further comprising moving the laser beam along the channel.

15. A glass processing apparatus for cutting a flexible glass substrate, the glass processing apparatus comprising:

a conveying path along which the flexible glass substrate may be conveyed through the glass processing apparatus;

a glass cutting apparatus for cutting the flexible glass substrate conveyed along the conveying path, the glass cutting apparatus comprising an optical delivery apparatus arranged and configured to direct a laser beam onto the flexible glass substrate conveyed along the conveying path for heating a region of the flexible glass substrate and introducing a first amount of tensile stress to the flexible glass substrate; and

a non-contact support member comprising a stress-inducing assembly comprising a stress-inducing feature allowing the flexible glass substrate to deform locally forming a local mechanical deformation introducing a second amount of tensile stress to the flexible substrate.

16. The glass processing apparatus of claim 15, wherein the second amount of tensile stress is less than the first amount of tensile stress.

17. The glass processing apparatus of claim 15 or claim 16 further comprising a pressurized gas delivery device arranged and configured to form the local mechanical deformation in the flexible glass substrate at the stress-inducing feature.

18. The glass processing apparatus of claim 15 or claim 16, wherein the non-contact support member comprises an air bar, the stress-inducing assembly comprises a roller that is recessed in the air bar and configured to contact the flexible glass substrate during a cutting operation thereby maintaining spacing between the air bar and the flexible glass substrate.

19. The glass processing apparatus of claim 18, wherein the stress-inducing assembly comprises multiple rollers, wherein a first roller contacts the flexible glass substrate at a first broad surface and a second roller contacts the flexible glass substrate at a second, opposite broad surface to apply the local mechanical deformation.

20. The glass processing apparatus of claim 15, wherein the stress-inducing feature is a trough into which the flexible glass substrate deforms, the local mechanical deformation is formed by directing a pressurized gas onto the flexible glass substrate thereby deforming the flexible glass substrate into the trough.

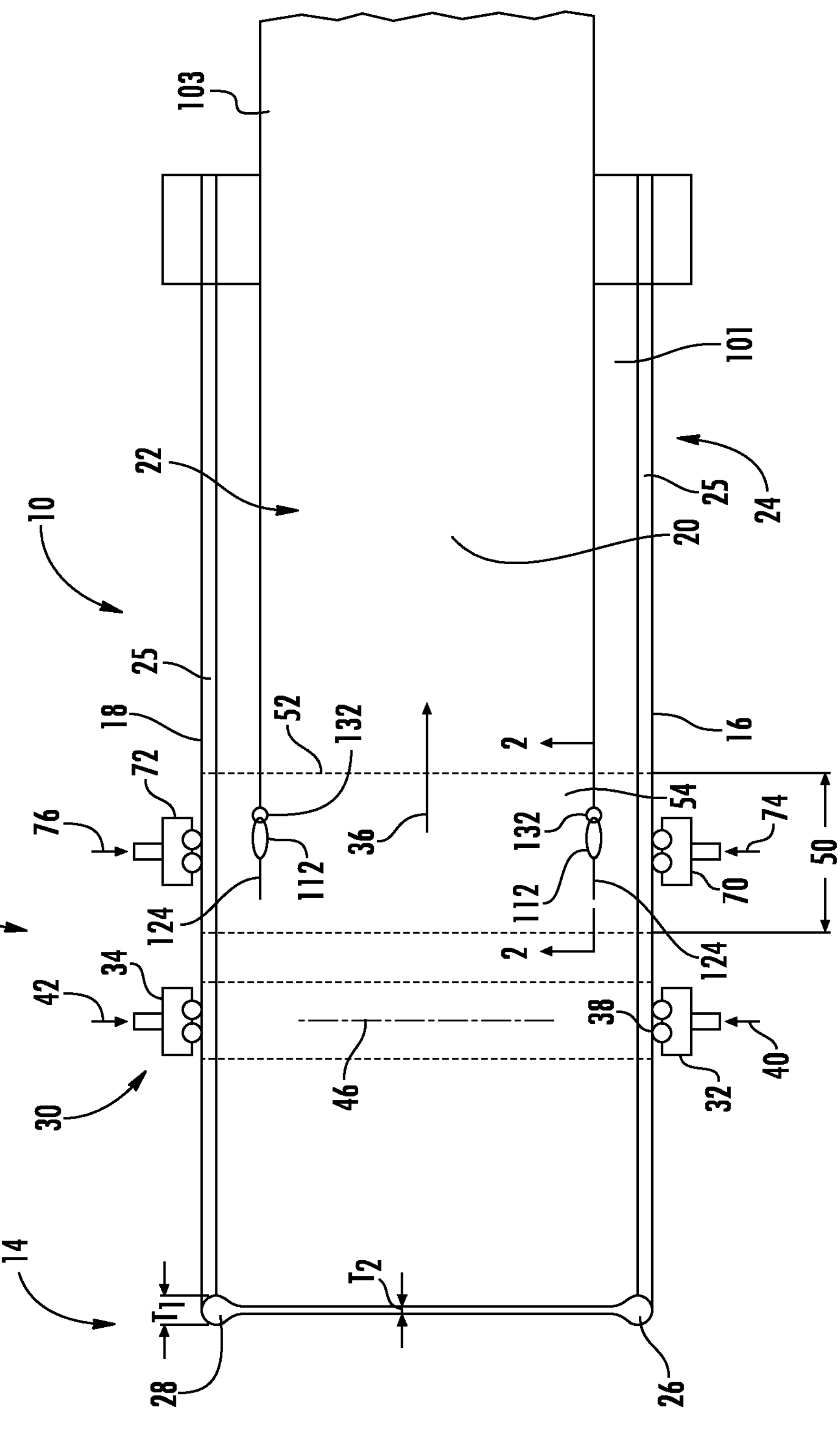
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FIG. 1

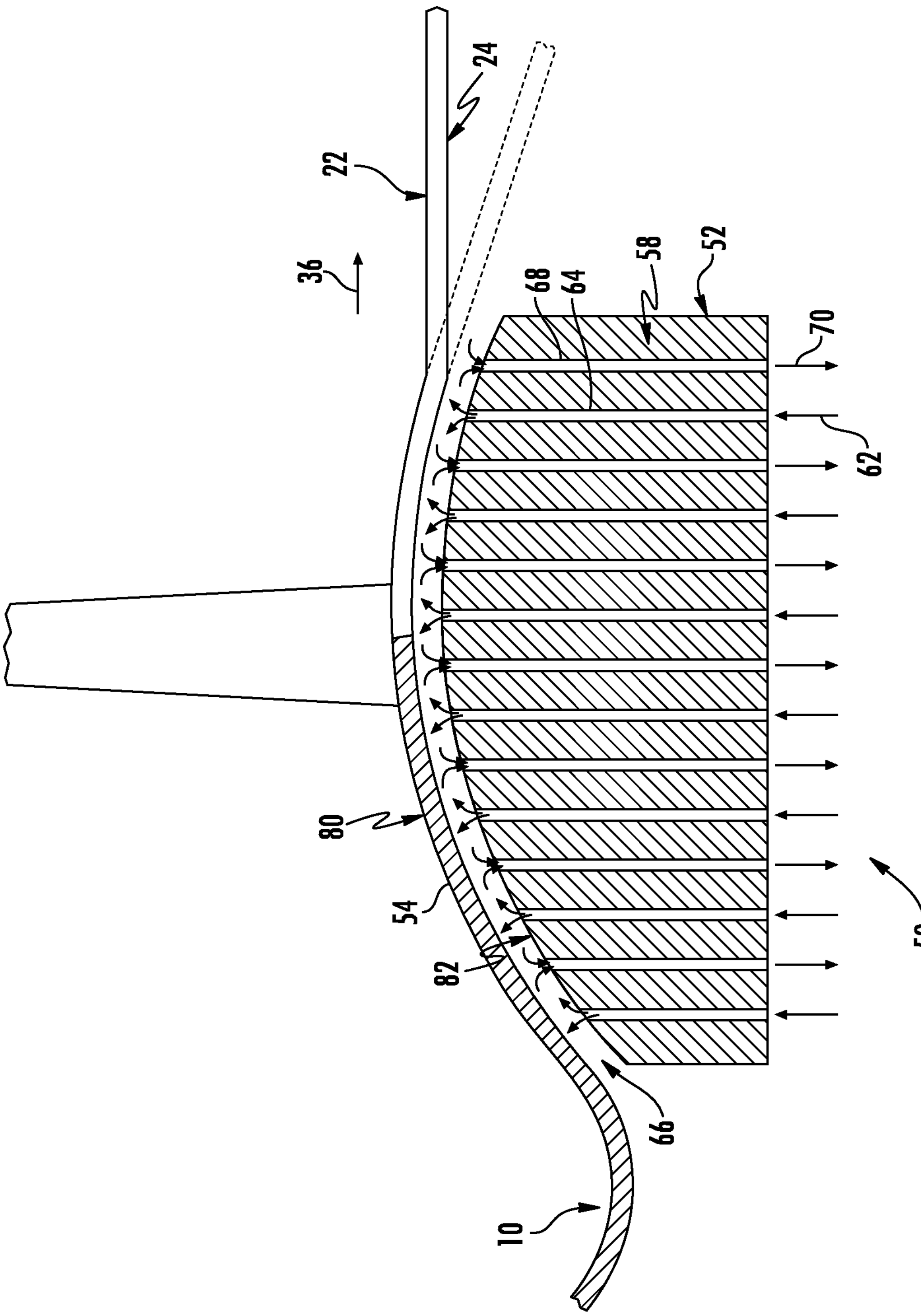

FIG. 2

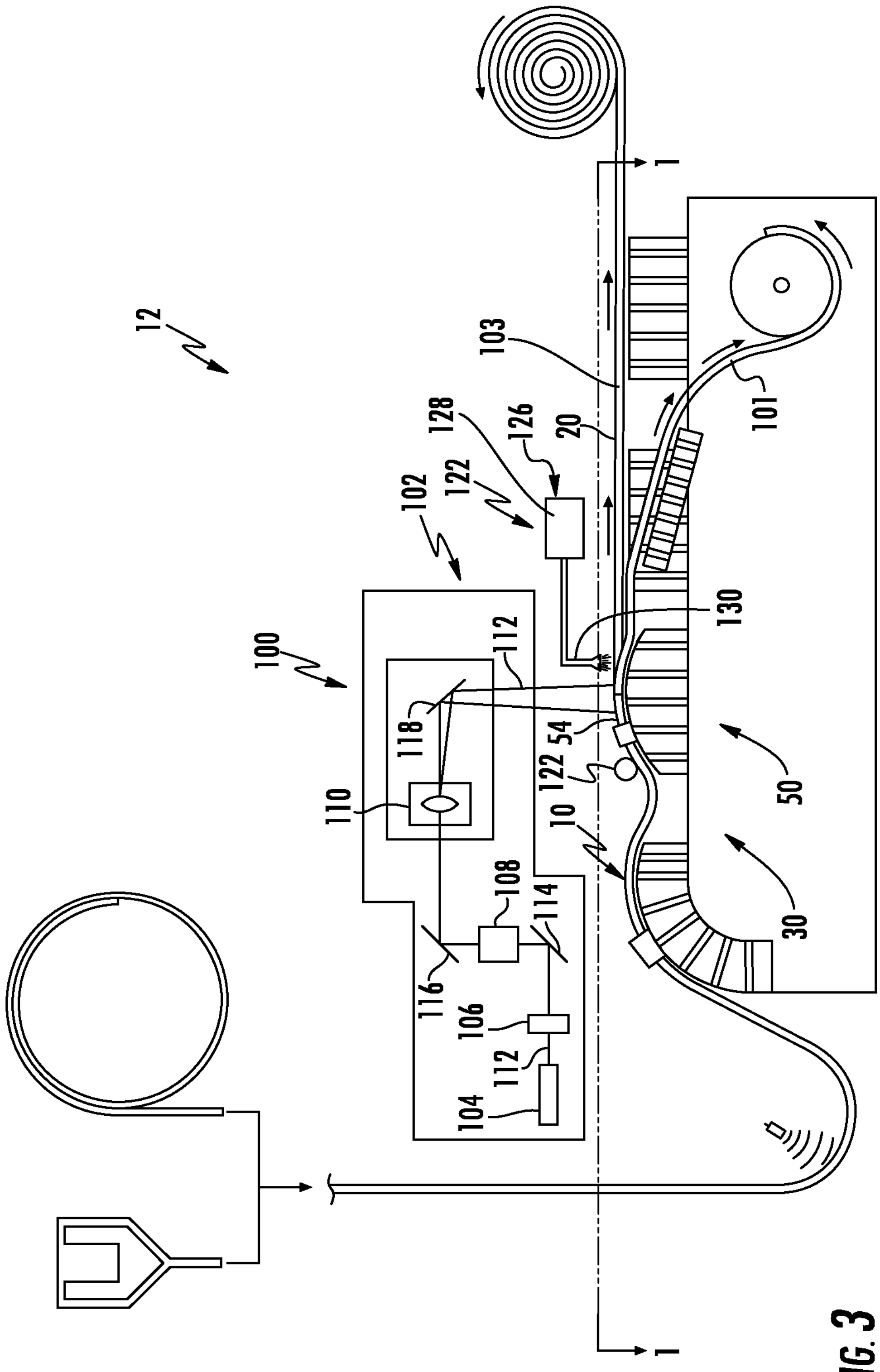
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FIG. 3

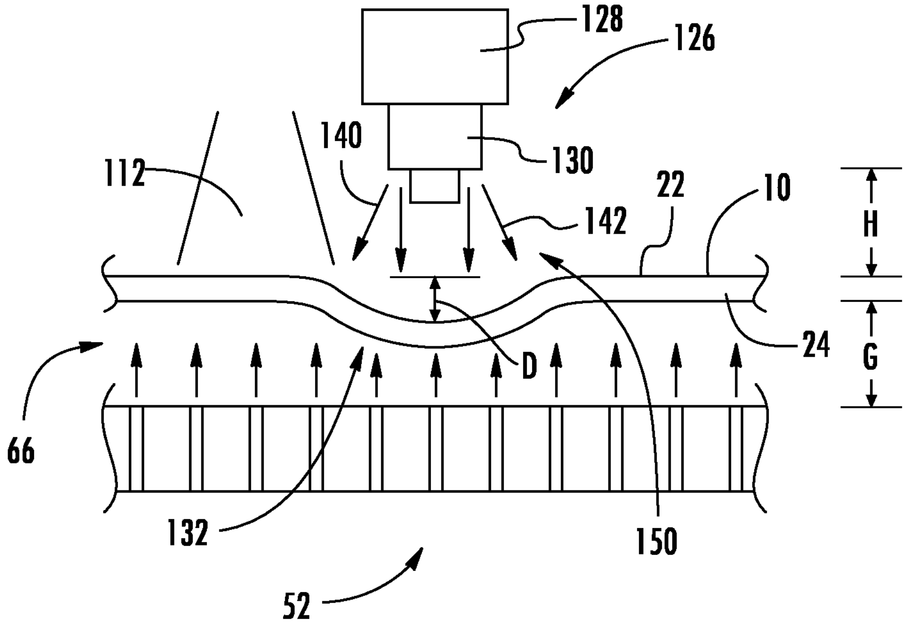
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FIG. 4

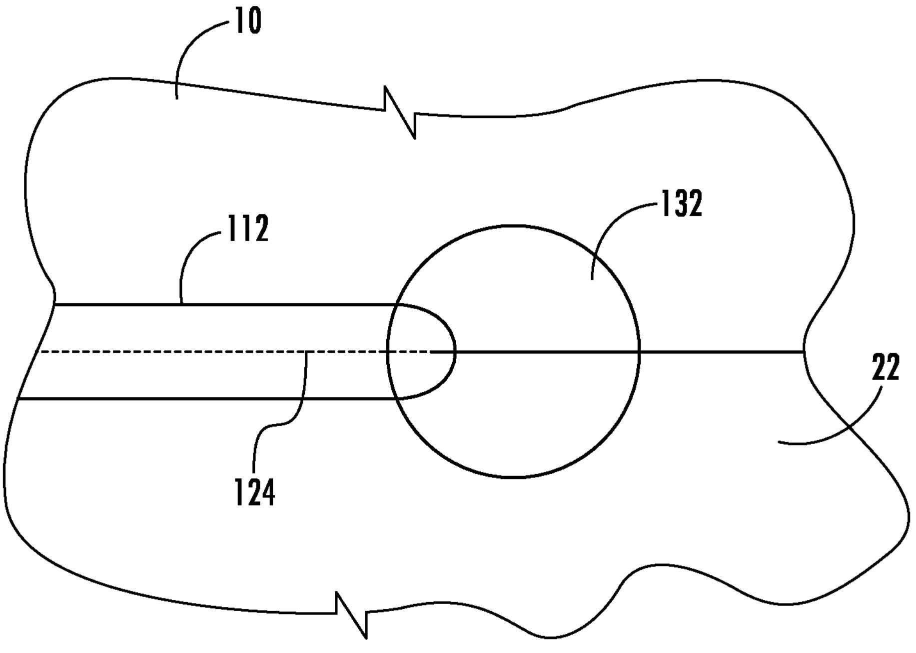
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FIG. 5

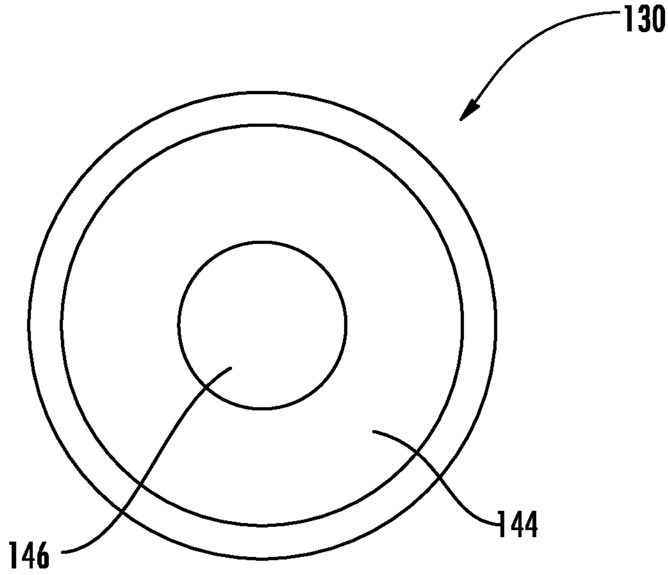

FIG. 6

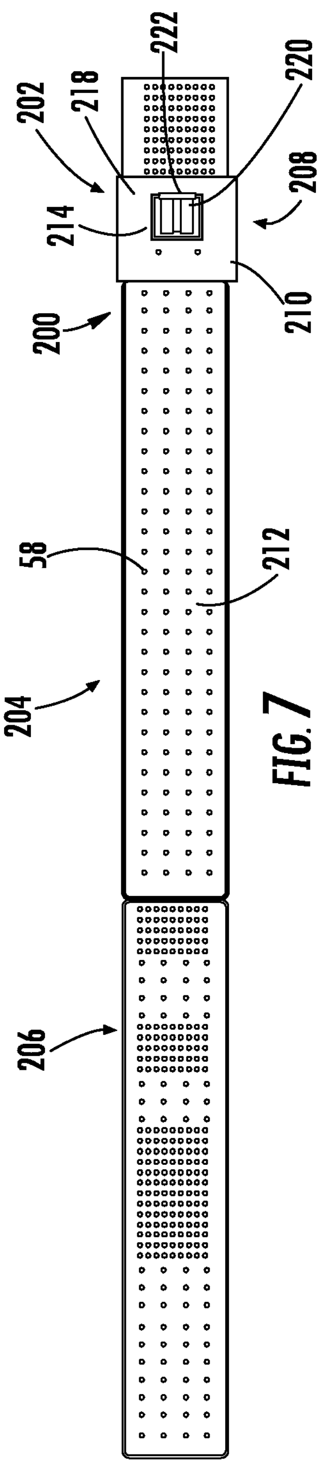
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FIG. 7

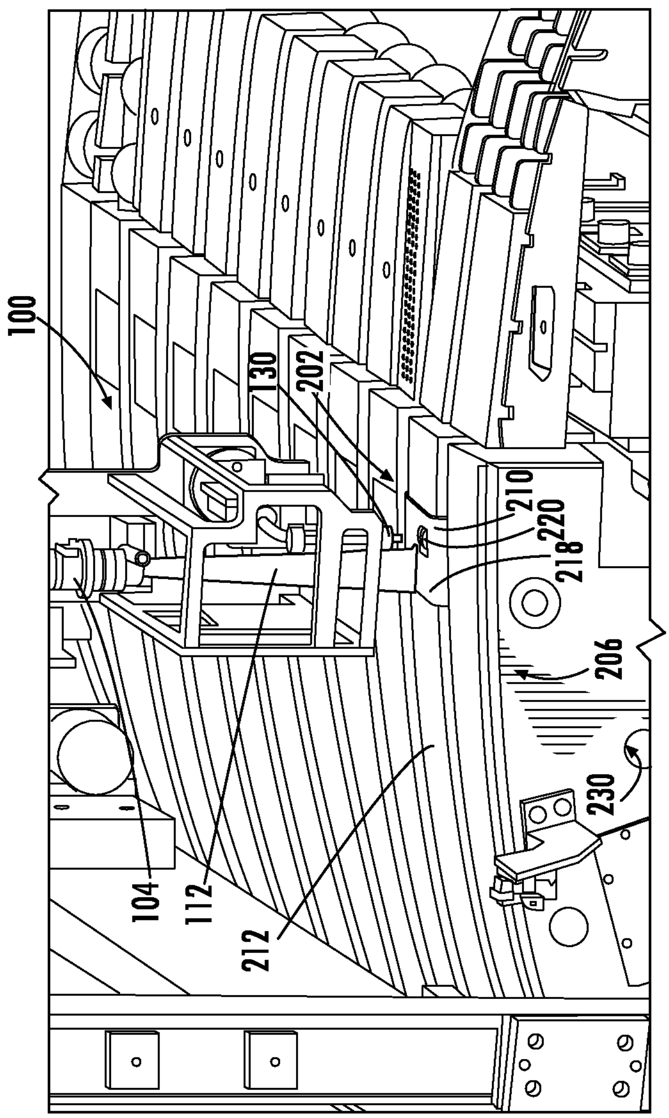
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FIG. 8

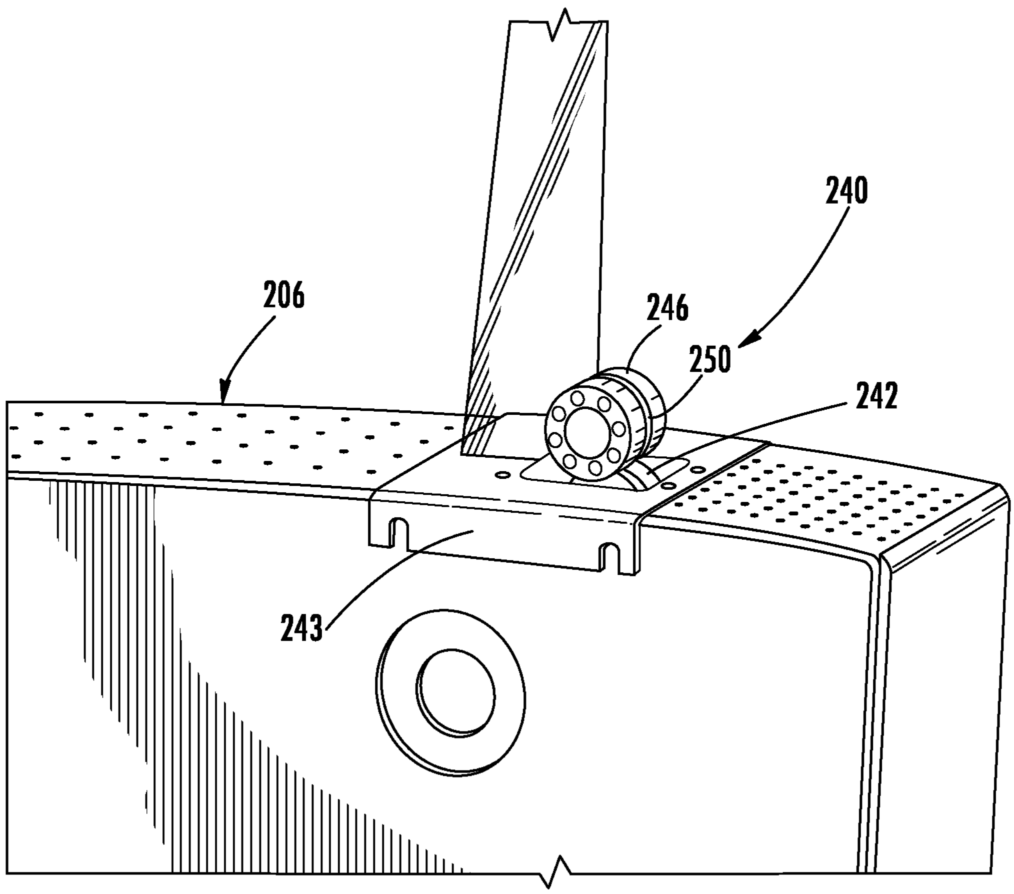

FIG. 10

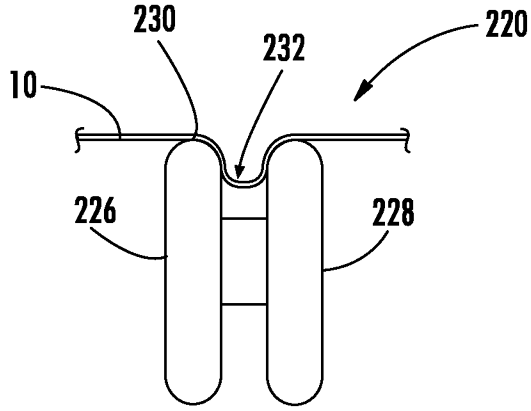

FIG. 9

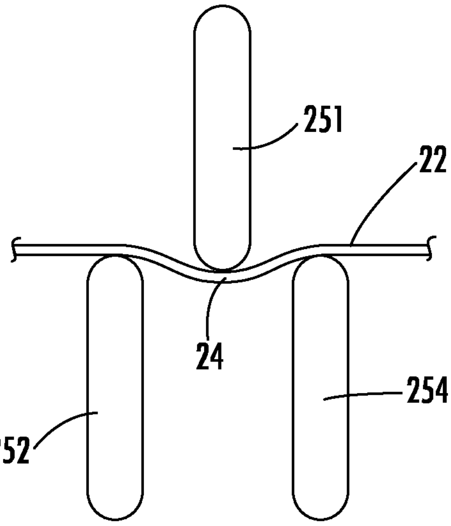

FIG. 11

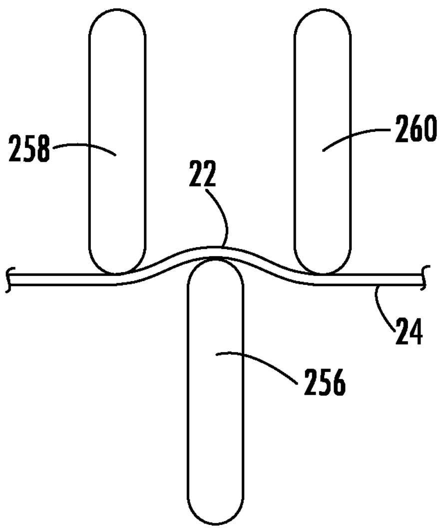

FIG. 12

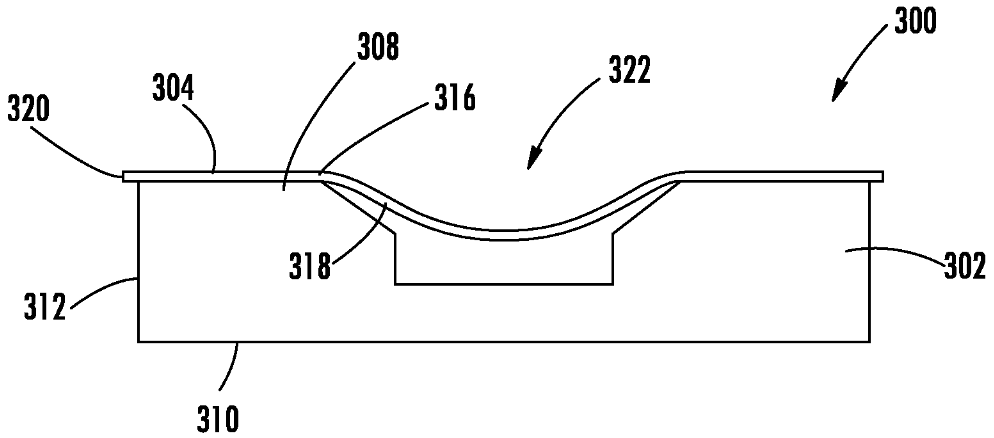
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FIG. 13

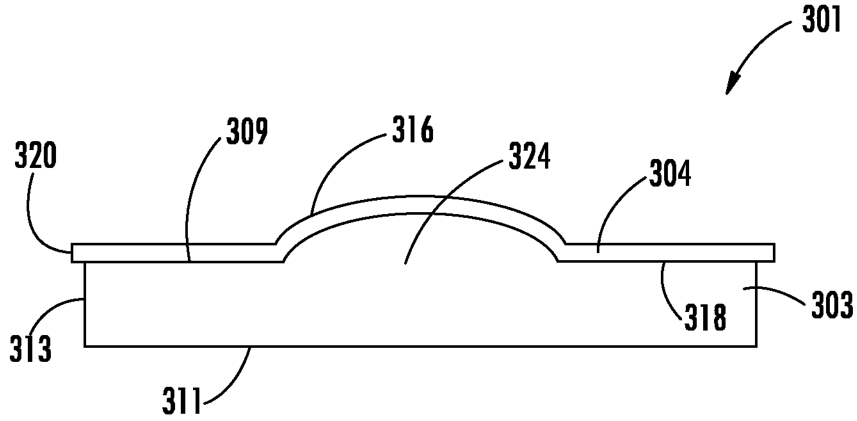
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FIG. 14

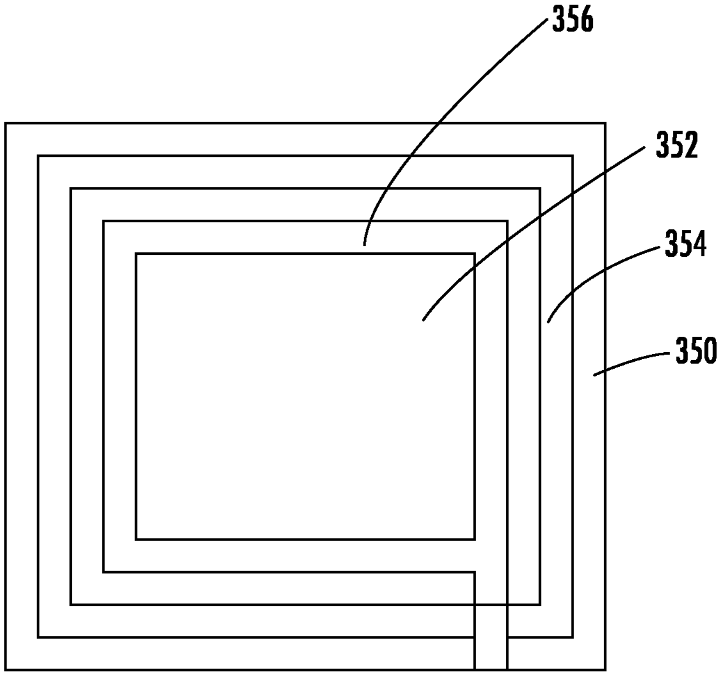

FIG. 15

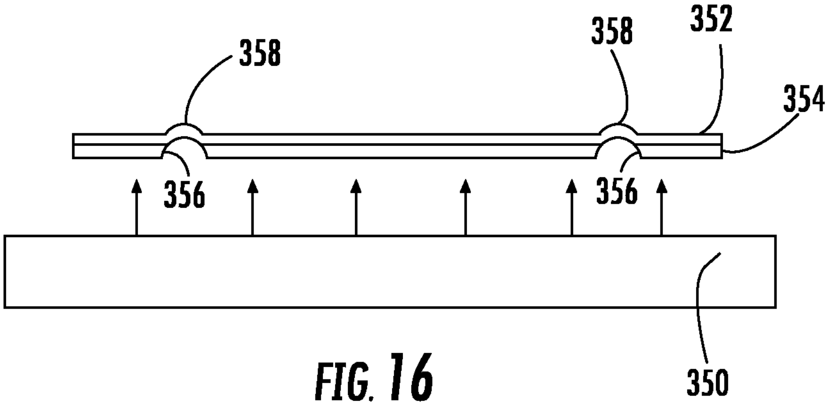

FIG. 16

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/040503

A. CLASSIFICATION OF SUBJECT MATTER
INV. C03B33/023 C03B33/03 C03B33/033 C03B33/09 B65G49/06
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)
C03B B65G

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2014/074400 A2 (CORNING INC [US]; CHANG CHESTER HANN HUEI [US]; FLEMING TODD BENSON [U) 15 May 2014 (2014-05-15) item 161,142,197; sentences 14-21, paragraph 53; claim 1; figures 2-3,6-9,14-16 paragraphs [0066] - [0068], [0082] - [0085], [0107] paragraphs [0114], [0116] -----	1-7,9, 10,15-20
X Y	US 2007/169849 A1 (YAHAGI SUSUMU [JP] ET AL) 26 July 2007 (2007-07-26) items 63,7a; paragraphs [0079], [0083] - [0084]; figures 5,8-10 -----	1,8 13,14
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
1 October 2015	08/10/2015

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	Gkerou, Elisavet

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/040503

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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X Y	US 2012/017642 A1 (TERANISHI YASUO [JP] ET AL) 26 January 2012 (2012-01-26) items G,R,8; paragraphs [0051], [0061], [0068]; claim 1; figures 5A-5C	11,12 13,14
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X	JP 2009 078502 A (MITSUBOSHI DIAMOND IND CO LTD) 16 April 2009 (2009-04-16) paragraph [0034]; figures 6-7,9-10	1,11,15
X	WO 2014/065248 A1 (NIPPON ELECTRIC GLASS CO [JP]) 1 May 2014 (2014-05-01) page 10; figures 3A,3b	1,2

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Information on patent family members

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