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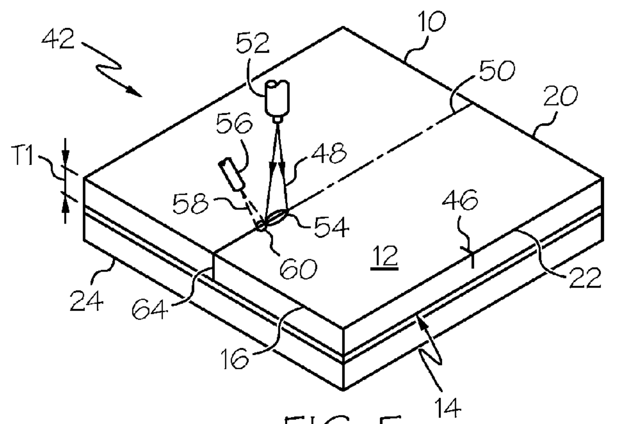

FIG. 5

(57) Abstract: A method of separating a glass sheet comprises providing a glass sheet including a first major surface opposing a second major surface. A layer of adhesive material bonds the second major surface of the glass sheet to a support surface of a carrier substrate and a thickness between the first and second major surfaces of the glass sheet is equal to or less than about 300 µm. The method comprises providing a first defect in the glass sheet and separating the glass sheet into a plurality of sub-sheets by traversing a beam of electromagnetic radiation over the first major surface along a first predetermined path to (a) transform the first defect into a first full body crack and (b) propagate the first full body crack along the first predetermined path, thereby producing a full body separation of the glass sheet while the glass sheet remains bonded to the support surface.

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METHODS FOR SEPARATING A GLASS SHEET

FIELD

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 62/022394 filed on July 09, 2014 the content of which is relied upon and incorporated herein by reference in its entirety.

BACKGROUND

[0002] The present disclosure relates generally to methods for separating a glass sheet and, more particularly, to methods for separating a thin glass sheet.

[0003] Glass sheets are commonly used, for example, in display applications such as, for example, liquid crystal displays (LCDs), electrophoretic displays (EPD), organic light emitting diode displays (OLEDs), plasma display panels (PDPs), or the like. Sometimes, a glass sheet is separated into multiple sub-sheets which can each be removed from the glass sheet to be used in a particular application.

[0004] Cutting of glass sheets is conventionally accomplished by using mechanical tools. Typically, the glass sheet is first scored, for example, by using a scoring tool (e.g. a sharp carbide wheel for example) that creates a score, or median crack, in the glass sheet, and incidentally, substantial damage to the glass sheet at the cut edge. However, alternative processes exist that use CO_2 laser radiation to heat the glass sheet and create tensile stress via a temperature gradient to produce a score. During laser scoring, an initiation defect is formed on the glass sheet to generate a median crack (also known as a partial vent or, simply, a vent). The vent is then propagated by a laser light formed into a beam that traverses across the surface of the glass sheet followed by a cooling area produced by a cooling nozzle. Heating of the glass sheet with a laser beam and quenching it immediately thereafter with a coolant creates a thermal gradient and a corresponding stress field that is responsible for the propagation of the vent. When the score is completed, bending or shear stress is then applied to the glass sheet that causes the vent to complete its propagation through the thickness of the sheet.

[0005] Although the laser scoring technique described above may be less damaging than mechanical scoring processes, the laser scoring process still generates damage to the glass sheet, e.g., particularly during the mechanical separation process involving the applied bending or shear stress. This potentially produces differences in edge strengths when the laser-incident side is evaluated in tensile versus compressive stress. Moreover, for both laser and mechanical scoring techniques, separation of the glass sheet requires at least two steps consisting of creating a score, and then applying a stress to the glass sheet (e.g. a bending stress) to separate the sheet along the score line. Furthermore, the scoring techniques typically generate debris, which can potentially contaminate the sub-sheets. Accordingly, it would be beneficial to provide a simplified separation process that can provide sub-sheets with minimal edge damage and contamination from debris generated in the separation process.

SUMMARY

[0006] There are set forth methods for separating a glass sheet that can provide a simplified separation process and can further provide sub-sheets with minimal edge damage and contamination from debris generated in the separation process.

[0007] In a first aspect, a method of separating a glass sheet comprises the step (I) of providing a glass sheet including a first major surface and a second major surface opposing the first major surface. A layer of adhesive material bonds the second major surface of the glass sheet to a support surface of a carrier substrate. A thickness between the first major surface and the second major surface of the glass sheet is equal to or less than about 300 μm. The method further includes the step (II) of providing a first defect in the glass sheet; and the step (III) of separating the glass sheet into a plurality of sub-sheets. Step (III) is carried out by traversing a beam of electromagnetic radiation over the first major surface along a first predetermined path to (a) transform the first defect into a first full body crack intersecting the first major surface and the second major surface of the glass sheet; and (b) propagate the first full body crack along the first predetermined path, thereby producing a full body separation of the glass sheet along the first predetermined path while the second major surface of the glass sheet remains bonded to the support surface of the carrier substrate.

[0008] In one example of the first aspect, step (II) further comprises providing a second defect in the glass sheet, and step (III) of separating the glass sheet into a plurality of sub-sheets further comprises traversing a beam of electromagnetic radiation over the first major surface along a second predetermined path to: (a) transform the second defect into a second full body crack intersecting the first major surface and the second major surface of the glass sheet; and (b) propagate the second full body crack along the second predetermined path, thereby producing a full body separation of the glass sheet along the second predetermined path while the second major surface of the glass sheet remains bonded to the support surface of the carrier substrate. In one example, the second predetermined path may intersect the first predetermined path.

[0009] In another example of the first aspect, the method further comprises the step (IV) of releasing at least a portion of at least one sub-sheet from the carrier substrate by producing a curvature in at least one of the second major surface of the glass sheet and the support surface of the carrier substrate. In one example, the step (IV) may comprise completely releasing at least one of the sub-sheets from the carrier glass while maintaining the curvature. In another example, the step (IV) may comprise producing a double bend curvature in the second major surface of the glass sheet by lifting an edge portion of one of the plurality of sub-sheets away from the carrier glass.

[0010] In yet another example of the first aspect, the method further comprises the step (IV) of providing a second defect in the carrier substrate; and the step (V) of separating the carrier substrate into a plurality of sub-carrier substrates by traversing a beam of electromagnetic radiation relative to the carrier substrate along a second predetermined path. In one example, the first predetermined path may be aligned with the second predetermined path. In another example, traversing the laser beam in step (V) may produce a scribe line in the carrier substrate along the second predetermined path. In one particular example, step (V) may further apply a bending force to the carrier substrate to separate the carrier substrate along the scribe line into the plurality of sub-carrier substrates. In still another example, traversing the electromagnetic radiation during step (V) may transform the second defect into a second full body crack extending through the carrier substrate and propagates the second crack along the second predetermined path produces a full body separation of the carrier substrate along the second predetermined path. In another example, each sub-carrier substrate provided by step (V) is bonded with a single corresponding one of the plurality of sub-sheets. In one particular example, the method may further comprise the step (VI) of releasing one of the sub-sheets from the corresponding sub-carrier substrate.

[0011] The first aspect may be provided alone or in combination with any one or more of the examples of the first aspect discussed above.

[0012] In a second aspect, a method of separating a glass sheet comprises the step (I) of providing a glass sheet including a first major surface, a second major surface opposing the first major surface, and a thickness between the first major surface and the second major surface equal to or less than about 300 μm. The second major surface of the glass sheet is bonded to a support surface of a carrier substrate. The method further includes the step (II) of providing a first defect in the glass sheet; and the step (III) of separating the glass sheet into a plurality of sub-sheets. Step (III) is carried out by traversing a beam of electromagnetic radiation over the first major surface along a first predetermined path to (a) transform the first defect into a first full body crack intersecting the first major surface and the second major surface of the glass sheet; and (b) propagate the first full body crack along the first predetermined path, thereby producing a full body separation of the glass sheet along the first predetermined path while the second major surface of the glass sheet remains bonded to the support surface of the carrier substrate. The method further includes the step (IV) of releasing at least a portion of at least one sub-sheet from the carrier substrate by producing a curvature in at least one of the second major surface of the glass sheet and the support surface of the carrier substrate.

[0013] In one example of the second aspect, the step (IV) further comprises completely releasing at least one of the sub-sheets from the carrier glass while maintaining the curvature.

[0014] In another example of the second aspect, the step (IV) comprises producing a double bend curvature in the second major surface of the glass sheet by lifting an edge portion of one of the plurality of sub-sheets away from the carrier glass.

[0015] In yet another example of the second aspect, the step (IV) translates at least a pair of facing edge surfaces of an adjacent pair of sub-sheets away from one another along a direction of the first major surface to create a lateral gap between the pair of facing edge surfaces.

[0016] In still yet another example of the second aspect, step (II) further comprises providing a second defect in the glass sheet, and step (III) of separating the glass sheet into a plurality of sub-sheets further comprises traversing a beam of electromagnetic radiation over the first major surface along a second predetermined path to: (a) transform the second defect into a second full body crack intersecting the first major surface and the second major surface of the glass sheet; and (b) propagate the second full body crack along the second predetermined path. As such, step (III) produces a full body separation of the glass sheet along the second predetermined path while the second major surface of the glass sheet remains bonded to the support surface of the carrier substrate. In one example, the second predetermined path can intersect the first predetermined path.

[0017] In still another example of the second aspect, step (I) includes the step of bonding the second major surface of the glass sheet to the support surface of the carrier substrate with a layer of adhesive material.

[0018] The second aspect may be provided alone or in combination with any one or more of the examples of the second aspect discussed above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] 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:

[0020] **FIG. 1** is a perspective view of a glass sheet;

[0021] **FIG. 2** is a perspective view of the carrier substrate;

[0022] **FIG. 3** is a perspective view of the glass sheet bonded to the carrier substrate to form a glass-carrier assembly;

[0023] **FIG. 4** illustrates a step of providing first and second defects in the glass sheet;

[0024] **FIG. 5** illustrates a step of traversing a beam of electromagnetic radiation over the glass sheet along a first predetermined path;

[0025] **FIG. 6** illustrates a full body cut in the glass sheet along the first predetermined path;

[0026] **FIG. 7** illustrates an example step of traversing the beam over the glass sheet along a second predetermined path;

[0027] **FIG. 8** illustrates a full body cut in the glass sheet along the second predetermined path;

[0028] **FIG. 9** illustrates an example step of forming a third defect in the carrier substrate;

[0029] **FIG. 10** illustrates an example step of traversing the laser over the carrier substrate along a third predetermined path to form a full body crack;

[0030] **FIG. 11** illustrates an example step of traversing the laser over the carrier substrate along the third predetermined path to form a partial crack;

[0031] **FIG. 12** illustrates the glass-carrier assembly separated into a plurality of sub-assemblies;

[0032] **FIG. 13** illustrates the step of releasing a sub-sheet from one of the plurality of sub-assemblies;

[0033] **FIG. 14** illustrates the step of producing a curvature in a second major surface of the glass sheet;

[0034] **FIG. 15** illustrates the step of producing a curvature in a support surface of the carrier substrate; and

[0035] **FIG. 16** is close up view of the glass-carrier assembly during the step illustrated in **FIG. 15**.

DETAILED DESCRIPTION

[0036] 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.

[0037] As illustrated in **FIG. 1**, an example method may comprise providing a glass sheet **10** including a first major surface **12** and a second major surface **14** opposing the first major surface **12**. A thickness **T1** between the first major surface **12** and the second major surface **14** of the glass sheet **10** can be equal to or less than about 300 μm, such as equal to or less than about 280 μm, such as equal to or less than about 230 μm, such as equal to or less than about 180 μm, such as equal to or less than about 100 μm, such as equal to or less than about 50 μm. The glass sheet **10** can include at least one edge to provide a curvilinear (e.g., oval, circular, etc.) polygonal (e.g., rectangular such as square, etc.) For instance, as illustrated, the glass sheet **10** can further include four edges **16**, **18**, **20**, **22** that define the boundaries of the first major surface **12** that may be arranged in the illustrated square shape although other rectangular shapes may be provided in further examples.

[0038] Turning to **FIG. 2**, the example method may further comprise providing a carrier substrate **24** that may be provided as a wide range of materials such as glass, ceramic, glass ceramic or other materials. Depending on processing techniques or other requirements, the carrier substrate **24** may or may not transmit light and can therefore be at least partially or entirely transparent, translucent or opaque. The carrier substrate **24** includes a first major surface **26**, an opposing second major surface **28**, and a thickness **T2** between the first and second major surfaces **26**, **28**. In some examples, the thickness **T2** may optionally be greater than or equal to 500 μm.

[0039] As further illustrated in **FIG. 2**, the carrier substrate **24** further includes edges **30**, **32**, **34**, **36** that define the boundaries of the second major surface **28**. In some examples, the carrier substrate **24** may have a geometrically similar or identical peripheral shape to the glass sheet **10**. For example, the illustrated carrier substrate **24** has an outer square shape that can be identical to the outer square shape of the glass sheet **10**. In further examples, the carrier substrate **24** may have a shape that, although not identical, is geometrically similar to the shape of the glass sheet **10**. For instance, the carrier substrate **24** may have a shape that is slightly larger but geometrically similar to the shape of the glass sheet **10**. Providing a larger carrier substrate **24** can help protect the edges of glass sheet **10** from damage. In some examples, the carrier substrate **24** may also have a shape that is substantially larger than the glass sheet **10**. In still further examples, the carrier substrate **24** may also have a shape that is smaller than the glass sheet **10**.

[0040] As shown in **FIG. 3**, the second major surface **14** of the glass sheet **10** may be bonded to a support surface (e.g. the first major surface **26**) of the carrier substrate **24**, thus forming a glass-carrier assembly **42**. A layer of adhesive material **40** may be used to bond the second major surface **14** of the glass sheet **10** to the support surface **26** of the carrier substrate **24**. Moreover, other bonding techniques such as, for example, hydrogen bonding may be used to bond the second major surface **14** of the glass sheet **10** to the support surface **26** of the carrier substrate **24**.

[0041] As can be seen in **FIGS. 1-3**, the major surfaces **12**, **14**, **26**, **28** of the glass sheet **10** and the carrier substrate **24** are all square in shape and have the same area. However, as mentioned above with respect to the edges, the major surfaces **12**, **14**, **26**, **28** may have different shapes such as, for example, rectangular shapes other than square, curvilinear shapes (e.g., circular, oval, etc.). Moreover, as mentioned previously, the first and second major surfaces **12**, **14** of the glass sheet **10** may have a shape or area that varies from the shape or area of the first and second major surfaces **26**, **28** of the carrier substrate **24**. For example, the first and second major surfaces **26**, **28** of the carrier substrate **24** may be rectangular and have a greater area than the square, first and second major surfaces **12**, **14** of the glass sheet **10**. As such, encounters from external objects may be first encountered by the carrier substrate **24** to thereby protect the edges of the glass substrate **10**. Also, the first and second major surfaces **26, 28** of the carrier substrate **24** may be rectangular and have a smaller area than the square, first and second major surfaces **12, 14** of the glass sheet **10**.

[0042] The example method can further include providing a first defect **44** and a second defect **46** in the glass sheet **10**, as shown in **FIG. 4**. The first and second defects **44**, **46** can be produced using various methods. For example, the first and second defects **44**, **46** may be produced by a laser pulse or by a mechanical tool such as a scribe, scoring wheel, diamond tip, indenter, etc. The first and second defects **44**, **46** may be formed on any of the edges **16**, **18**, **20**, **22** of the glass sheet **10** or the first and second defects **44**, **46** may be formed on the first major surface **12** of the glass sheet **10** away from the edges **16**, **18**, **20**, **22**. In the present example, the first defect **44** is formed on the edge **16** of the glass sheet **10** and the second defect **46** is formed on the edge **22** of the glass sheet **10**.

[0043] The example method can further include separating the glass sheet **10** into a plurality of sub-sheets. For example, the glass sheet **10** may be separated into a plurality of sub-sheets by traversing a beam of electromagnetic radiation **48** over the first major surface **12** along a first predetermined path **50**, as shown in **FIG. 5**. The first predetermined path **50** in the present example comprises a straight line that extends from the edge **16** of the glass sheet **10** at the location of the first defect **44** to the edge **20** of the glass sheet **10**. However, the first predetermined path **50** in other examples may comprise a curve. Moreover, the first predetermined path **50** may extend from the edge **16** of the glass sheet **10** at the location of the first defect **44** to any other edge of the glass sheet **10**. Furthermore, the first predetermined path **50** may comprise a closed path that is completely confined within the boundaries of the first major surface **12** such that it does intersect with any edge of the glass sheet **10**. The first predetermined path **50** may comprise any path that extends along or across the first major surface **12** of the glass sheet **10**.

[0044] A moveable laser irradiation device **52** can be used to produce and translate the beam of electromagnetic radiation **48** along the first predetermined path **50**. As the beam **48** is traversed along the first predetermined path **50**, a heated region **54** is formed on the first major surface **12**. The beam **48** can be followed, optionally, with a cooling device **56** that applies a cooling fluid **58** to the glass sheet **10** along the first predetermined path **50** subsequent to the heating of the beam **48**, as further shown in **FIG. 5**. The cooling fluid **58** can be a liquid or gas or combination of liquid and gas. The application of the cooling fluid **58** produces a cooled region **60** on the first major surface **12** that is substantially lower in temperature than the heated region **54**. As a result of this temperature difference, a thermal stress is generated in the glass sheet **10** that causes the first defect **44** to transform into a first full body crack **64** intersecting the first major surface **12** and the second major surface **14** of the glass sheet **10**. The first full body crack **64** then propagates along the first predetermined path **50** as the beam **48** and cooling fluid **58** are traversed along the first predetermined path **50**. As shown, optionally, the first full body crack **64** may be produced without propagating into the carrier substrate **24**. As can be seen in **FIG. 6**, once the beam **48** and cooling fluid **58** completely traverse the first predetermined path **50**, a full body separation of the glass sheet **10** is produced along the first predetermined path **50** from the first major surface **12** to the second major surface **14**, thus separating the glass sheet **10** into two sub-sheets **68**, **70**. Moreover, because the second major surface **14** of the glass sheet **10** remains bonded to the support surface **26** of the carrier substrate **24** during and after separation, the two sub-sheets **68**, **70** remain substantially in contact or in close proximity with each other along their line of separation.

[0045] The step of separating the glass sheet **10** into a plurality of sub-sheets may further comprise traversing the beam of electromagnetic radiation **48** over the first major surface **12** along a second predetermined path **78**, as shown in **FIG. 7**. The second predetermined path **78** in the present example comprises a straight line that extends from the edge **22** of the glass sheet **10** at the location of the second defect **46** to the edge **18** of the glass sheet **10**. Moreover, as shown, the second predetermined path **78** can intersect with the first predetermined path **50**. As shown, the second predetermined path 78 may also be oriented perpendicular to the first predetermined path **50**. However, the second predetermined path **78** need not be perpendicular to the first predetermined path **50**. Rather, second predetermined path **78** can form any angle with the first predetermined path **50**. Moreover, the second predetermined path **78** in some examples may comprise a curve rather than a straight line. Furthermore, the second predetermined path **78** may extend from the edge **22** of the glass sheet **10** at the location of the second defect **46** to any other edge of the glass sheet **10**. Still further, the second predetermined path **78** may comprise a closed path that is completely confined within the boundaries of the first major surface **12** such that it does intersect with any edge of the glass sheet **10**. The second predetermined path **78** may comprise any path that extends along or across the first major surface **12** of the glass sheet **10** that intersects with the first predetermined path **50**.

[0046] As the beam **48** is traversed along the second predetermined path **78**, the heated region **54** is once again formed on the first major surface **12**. The beam **48** can, optionally, be followed with the cooling device **56** to apply the cooling fluid **58** to the glass sheet **10** along the second predetermined path **78** subsequent to the heating of the beam **48**, thus forming the cooled region **60**. A thermal stress is generated in the glass sheet **10** that causes the second defect **46** to transform into a second full body crack **82** intersecting the first major surface **12** and the second major surface **14** of the glass sheet **10**. The second full body crack **82** then propagates along the second predetermined path **78** as the beam **48** and cooling fluid **58** are traversed along the second predetermined path **78**.

[0047] As shown, optionally, the second full body crack **82** may be produced without propagating into the carrier substrate **24**. Eventually, the second full body crack **82** will propagate along the second predetermined path **78** to the separation line of the two sub-sheets **68**, **70**. As the two sub-sheets **68**, **70** are substantially in contact or in close proximity with each other along their line of separation, the second full body crack **82** will continue to propagate past the separation line of the two sub-sheets **68**, **70** without the need of an additional defect. Thus, as can be seen in **FIG. 8**, once the beam **48** and cooling fluid **58** completely traverse the second predetermined path **78**, a full body separation of the glass sheet **10** is produced along the second predetermined path **78** from the first major surface **12** to the second major surface **14**, thus separating the glass sheet **10** into four sub-sheets **86**, **88**, **90**, **92**. This separation along the second predetermined path **78** can also be referred to as a cross-cut, since the separation along the second predetermined path **78** crosses the separation of the glass sheet **10** along the first predetermined path **50**. Because the second major surface **14** of the glass sheet **10** remains bonded to the support surface **26** of the carrier substrate **24** during and after separation, the four sub-sheets **86**, **88**, **90**, **92** remain substantially in contact or in close proximity with each other along the lines of separation. In this example, for sub-sheets **86, 88, 90, 92** were formed requiring half the number or less of initiation defects. As the number of sub-sheets increases, the relative number of required initiation defects decreases.

[0048] Although the example method described thus far separates the glass sheet **10** along two predetermined paths of separation, the method in other examples may separate the glass sheet **10** along any number of predetermined paths of separation. In such examples, a defect can similarly be formed for each predetermined path and the beam **48** and optional cooling fluid **58** may similarly be applied to the glass sheet **10** to transform the defect into a crack and propagate the crack along the corresponding predetermined path. If the predetermined path happens to cross a line of separation between two sub-sheets of the glass sheet **10**, the crack will continue to propagate past the line of separation since the sub-sheets would remain in thermal contact due to the bonding of the glass sheet **10** and carrier substrate **24**.

[0049] Once the glass sheet **10** has been separated into a desired number of sub-sheets, one or more of the sub-sheets may be released from the glass-carrier assembly **42** in a variety of ways. For example, **FIGS. 9-13** illustrate one way of releasing one or more of the sub-sheets from the glass-carrier assembly **42**. As shown in **FIG. 9**, after the glass sheet **10** has been separated into the four sub-sheets **86**, **88**, **90**, **92**, the method can comprise the step of providing a third defect **102** in the carrier substrate **24**. The third defect **102** may be formed on any of the edges **30**, **32**, **34**, **36** of the carrier substrate **24** or the third defect **102** may be formed on the second major surface **28** of the carrier substrate **24** away from the edges **30**, **32**, **34**, **36**. For illustrative purposes, third defect **102** is shown formed on the edge **30** of the carrier substrate **24**.

[0050] After the third defect **102** has been formed, the carrier substrate **24** may be separated into a plurality of sub-carrier substrates by traversing the beam of electromagnetic radiation **48** relative to the carrier substrate **24** along a third predetermined path **112**, as shown in **FIG. 10**. Preferably, the third predetermined path **112** is aligned with the first predetermined path **50** and comprises a straight line that extends from the edge **30** of the carrier substrate **24** at the location of the third defect **102** to the edge **34** of the carrier substrate **24**. However, the third predetermined path **112** may comprise any path that extends across the second major surface **28** of the carrier substrate **24**.

[0051] As the beam **48** is traversed along the third predetermined path **112**, the heated region **54** is formed on the second major surface **28** of the carrier substrate **24**. The beam **48** can be followed with the cooling device **56** to apply the cooling fluid **58** to the carrier substrate **24** along the third predetermined path **112** subsequent to the heating of the beam **48**, thus forming the cooled region **60**. A thermal stress is generated in the carrier substrate **24** that causes the third defect **102** to transform into a crack **116** that is then propagated along the third predetermined path **112** as the beam **48** and the cooling fluid **58** are traversed. In the present embodiment, the crack **116** is a full body crack that extends through the entire thickness **T2** of the carrier substrate **24**, thus producing a full body separation of the carrier substrate **24** along the third predetermined path **112**. However, in other embodiments, the crack **116** may be a partial crack that propagates only partially through the thickness **T2** of the carrier substrate **24**, thus forming a scribe line **118** along the third predetermined path **112**, as shown in **FIG. 11**. In such embodiments, a bending force may be subsequently applied to the carrier substrate **24** to then separate the carrier substrate **24** along the formed scribe line **118** into a plurality of sub-carrier substrates. Besides use of electromagnetic radiation, the carrier substrate **24** can also be separated by use of mechanical scribing or other methods. The methods to separate the carrier substrate **24** and the glass sheet **10** are not required to be the same.

[0052] The carrier substrate **24** may be separated into any number of sub-carrier substrates using the scribe and/or full body cut techniques described above. For example, **FIG. 12** shows the glass-carrier assembly **42** after the carrier substrate **24** has been separated along two predetermined paths aligned with the first and second predetermined paths **50**, **78** that the glass sheet **10** was separated along. As can be seen, the carrier substrate **24** has been separated into the four sub-carrier substrates **120, 122, 124, 126**. Consequently, the glass-carrier assembly **42** is separated into the four sub-assemblies **130, 132, 134, 136**, wherein each sub-carrier substrate **120, 122, 124, 126** is bonded with a single corresponding one of the plurality of sub-sheets **86**, **88**, **90**, **92** to form one of the four sub-assemblies **130, 132, 134, 136**. Each of these sub-assemblies **130, 132, 134, 136** may be used for separate applications. Moreover, because each sub-sheet **86**, **88**, **90**, **92** is part of a separate sub-assembly **130, 132, 134, 136**, each sub-sheet **86**, **88**, **90**, **92** may be released from its corresponding sub-carrier substrate **120, 122, 124, 126** without the risk of bringing edges of the sub-sheet into contact with the remaining sub-sheets that may otherwise damage the edges. For example, **FIG. 13** shows the step of releasing sub-sheet **86** of sub-assembly **130** from the sub-carrier substrate **120**. The sub-assembly **130** has been isolated from the remaining sub-assemblies **132, 134, 136**. As such, the sub-sheet **86** may be released without the risk of bringing edges of the sub-sheet **86** into contact with the remaining sub-sheets **88**, **90**, **92**.

[0053] Although the releasing steps described above involve separating the carrier substrate **24** into a plurality of sub-carriers after the glass sheet **10** has been separated, the releasing steps in other examples may separate the carrier substrate **24** into a plurality of sub-carriers before the glass sheet **10** is separated. Moreover, in other examples, scribe lines may be first formed in the carrier substrate **24**, followed by the separation of the glass sheet **10**, and then the bending stress can be applied to the carrier substrate **24** to separate the carrier substrate **24** along the scribe lines and into a plurality of sub-carriers.

[0054] **FIGS. 14-16** illustrate alternative steps of releasing one or more of the sub-sheets from the glass-carrier assembly **42** that do not include separating the carrier substrate **24** into sub-carrier substrates. For example, after the glass sheet **10** of the glass-carrier assembly **42** has been separated into a plurality of sub-sheets, the method can comprise the step of releasing at least a portion of at least one sub-sheet from the carrier substrate **24** by producing a curvature in at least one of the second major surface **14** of the glass sheet **10** and the support surface **26** of the carrier substrate **24**. For instance, **FIGS. 14** and **15** show the glass-carrier assembly **42** after the glass sheet **10** has been separated into four sub-sheets **86**, **88**, **90**, **92**. As shown in **FIG. 14**, a double bend curvature can be produced in the second major surface **14** of the glass sheet **10** by lifting an edge portion **142** of one of the plurality of sub-sheets **86** away from the carrier substrate **24**. In just one example, the edge portion **142** may be lifted away such that facing edge surfaces **144**, **146** of adjacent sub-sheets **86**, **92** immediately begin moving away from one another while the edge portion **142** is lifted away. For instance, in one example, the double bend curvature allows the facing edge surfaces **144, 146** to be maintained substantially parallel with each other while the edge portion **142** is lifted away. As the facing edge surfaces remain substantially parallel, the facing edge surfaces **144, 146** can begin immediately moving away from one another as the edge portion **142** is lifted away. However, there may be embodiments wherein the facing edge surfaces **144**, **146** are slightly non-parallel while the edge portion **142** is lifted away. The double bend curvature permits the edge surfaces **144**, **146** to remain substantially parallel or slightly non-parallel while the edge portion **142** is lifted away to peel the sub-sheet **86** away from the carrier substrate **24**. By lifting the edge portion **142** away from the carrier substrate **24** in this manner, edges **150**, **152** of the sub-sheet **86** are prevented from rubbing against the edge surface **146**. As such, damage to the edge surface **146** can be avoided that may otherwise occur with other releasing techniques. The sub-sheet **86** may be completely released from the carrier substrate **24** while maintaining this double bend curvature. However, there may be embodiments wherein the double bend curvature is maintained only while a portion of the sub-sheet **86** is being released from the carrier substrate **24**. Also, the sub-sheet **86**

can optionally be released from the carrier substrate **24** using other single-bend geometries, as well, and geometries that release the sub-sheet **86** starting from the exterior edge instead of the interior edge surface **144** as shown in **FIG. 14**.

[0055] Turning to **FIGS. 15 & 16**, in still another example, a curvature may be produced in the support surface **26** of the carrier substrate **24** to release at least a portion of the sub-sheet **86** from the carrier substrate **24**. As can be seen in **FIGS. 15 & 16**, producing the curvature translates the pair of facing edge surfaces **144**, **146** of the adjacent pair of sub-sheets **86**, **92** away from one another along a direction **D** of the first major surface **12** to create a lateral gap **156** between the pair of facing edge surfaces **144**, **146**. The presence of the gap **156** can prevent the edges **150**, **152** of the sub-sheet **86** from rubbing against the edge surface **146** as the edge portion **142** of the sub-sheet **86** is lifted away from the carrier substrate **24**. Moreover, a double or single bend curvature can be further produced in the second major surface **14** of the glass sheet **10** while lifting the edge portion **142** away from the carrier substrate **24** to help further prevent the edges **150**, **152** of the sub-sheet **86** from rubbing against the edge surface **146** as the edge portion **142** of the sub-sheet **86** is lifted away. The sub-sheet **86** may be completely released from the carrier substrate **24** while maintaining the curvature in the support surface **26** of the carrier substrate **24**. However, there may be embodiments wherein the curvature in the support surface **26** of the carrier substrate **24** is maintained only while a portion of the sub-sheet **86** is being released from the carrier substrate **24**.

[0056] Although **FIGS. 14-16** illustrate steps of releasing one or more of the sub-sheets from the glass-carrier assembly **42** that do not include separating the carrier substrate **24** into sub-carrier substrates, there may be embodiments wherein one or more of the sub-sheets are released from the glass-carrier assembly **42** that include both separating the carrier substrate **24** into sub-carrier substrates and producing a curvature in at least one of the second major surface **14** of the glass sheet **10** and the support surface **26** of the carrier substrate **24** as described above. For example, after the glass sheet **10** of the glass-carrier assembly **42** has been separated into four sub-sheets **86**, **88**, **90**, **92**, the carrier substrate **24** may be separated along a single predetermined path to produce two sub-assemblies that each comprise two sub-sheets bonded to a sub-carrier. A curvature may then be produced in at least one of the second major surface **14** of the glass sheet **10**

and the support surface **26** of the carrier substrate **24** to remove one of the sub-sheets from one of the sub-assemblies.

[0057] The example method described above can provide a number of advantages over typical laser scoring techniques. For instance, typical laser scoring techniques for glass sheets require at least two steps consisting of creating a score, and then applying a stress to the glass sheet to separate the sheet along the score line. Also, mechanical defects may occur during the mechanical separation process involving the applied bending or shear stress. This potentially produces differences in edge strengths when the laser-incident side is evaluated in tensile versus compressive stress. However, the method described above simplifies the separation process by creating full body cracks **64**, **82** in the glass sheet **10** that separate the glass sheet **10** without the need for an additional step of applying a stress to the glass sheet **10**. As another advantage, the method described above minimizes the amount of edge damage produced during cross-cutting applications that have intersecting lines of separation. Because the glass sheet **10** in the example method is bonded (e.g., with adhesive) to the carrier substrate **24**, any sub-sheets formed will remain substantially in contact or in close proximity with each other along their lines of separation. Thus, if any cracks are propagated across an existing line of separation, it is not necessary to produce another edge defect to continue propagation of the crack across the line. Indeed, as can be seen in **FIG. 8**, the sub-sheet **90** was formed without the need to create any edge defects along its perimeter. As yet another advantage, the method described above can help prevent edge damage to the glass sub-sheets that can occur while they are being removed from the carrier substrate **24** by separating the glass-carrier assembly **42** into a plurality of isolated sub-assemblies that each have a single sub-sheet or by producing a curvature in at least one of the second major surface **14** of the glass sheet **10** and the support surface **26** of the carrier substrate **24**.

[0058] Examples will now be described of experiments that the inventors conducted using the method described above.

EXAMPLE 1

[0059] In one example, a glass sheet comprising Corning® Willow® Glass (available from Corning Incorporated, Corning, NY) and having a thickness of 130 um was bonded to a carrier glass substrate comprising Corning® EAGLE XG® Glass (available from Corning Incorporated, Corning, NY) and having a thickness of 700 μm. The carrier glass substrate was coated with plasma polymerized teflon (-PPT) to facilitate bonding and debonding. Defects were then generated in an edge region of the glass sheet using a diamond tip or a scoring wheel. Afterwards, CO_2 laser cross-cutting of the glass sheet was carried out using a 400 W RF-excited CO_2 laser. The laser beam was expanded and focused using an asymmetrical aspheric lens to produce a rectangular footprint on the surface of the glass sheet having a dimension of roughly 45 mm long and 1.5 wide. The laser beam had a top-hat intensity profile on both its long (45 mm) and short (1.5 mm) axis. Cutting was carried out along the long axes of the footprint. A mist jet followed the laser beam to quench the glass sheet using de-ionized water as a coolant. The laser beam and mist jet were operated under the following conditions during the cross-cutting:

Laser power: 160 W

Water flow: 10 sccm

Air Flow: 3 lpm

Cutting speed: 250 mm

[0060] A first cut was made with the CO_2 laser followed by a second cut that intersected the first cut. Full-body cracks were observed for both the first and second cuts. The second cut was observed to propagate through the first cut without hindrance. Glass sub-sheets produced by the cross-cutting process above were extracted with ease from the carrier substrate.

EXAMPLE 2

[0061] In another example, a glass sheet comprising Corning® Willow® Glass was bonded to a carrier glass substrate comprising Corning® EAGLE XG® Glass to produce a glass-carrier assembly. The carrier glass substrate was coated with PPT to facilitate bonding and debonding. Defects were then generated in edge regions of both the glass sheet and carrier substrate using a diamond tip or a scoring wheel. The glass sheet was cut using the same parameters described in Example 1. However, prior to cutting, a scribe line was formed on the carrier substrate using the laser beam. A bending stress was then applied to the glass-carrier assembly to propagate the crack of the scribe line and break the carrier glass along the scribe line. The crack did not propagate into the glass sheet. A full-body crack was subsequently initiated in the glass sheet and propagated to separate the glass sheet.

EXAMPLE 3

[0062] In another example, a glass sheet comprising Corning® Willow® Glass was bonded to a carrier glass substrate comprising Corning® EAGLE XG® Glass to produce a glass-carrier assembly. The carrier glass substrate was coated with PPT to facilitate bonding and debonding. Defects were then generated in an edge region of the glass sheet using a diamond tip or a scoring wheel. The glass sheet was then cut using the same parameters described in Example 1. Afterwards, a laser cross-scribe process was carried out on the carrier glass substrate. The laser scribe lines were carefully aligned with cuts on the glass sheet. A bending stress was then applied to the glass-carrier assembly to break the carrier glass along the scribe lines.

[0063] 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 separating a glass sheet comprising:

(I) providing a glass sheet including a first major surface and a second major surface opposing the first major surface, wherein a layer of adhesive material bonds the second major surface of the glass sheet to a support surface of a carrier substrate, and a thickness between the first major surface and the second major surface of the glass sheet is equal to or less than about 300 μm;

(II) providing a first defect in the glass sheet; and

(III) separating the glass sheet into a plurality of sub-sheets by traversing a beam of electromagnetic radiation over the first major surface along a first predetermined path to:

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

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

2. The method of claim 1, wherein step (II) further comprises providing a second defect in the glass sheet, and step (III) of separating the glass sheet into a plurality of sub-sheets further comprises traversing a beam of electromagnetic radiation over the first major surface along a second predetermined path to: (a) transform the second defect into a second full body crack intersecting the first major surface and the second major surface of the glass sheet; and (b) propagate the second full body crack along the second predetermined path, thereby producing a full body separation of the glass sheet along the second predetermined path while the second major surface of the glass sheet remains bonded to the support surface of the carrier substrate.

3. The method of claim 2, wherein the second predetermined path intersects the first predetermined path.

4. The method of claim 1, further comprising the step (IV) of releasing at least a portion of at least one sub-sheet from the carrier substrate by producing a curvature in at least one of the second major surface of the glass sheet and the support surface of the carrier substrate.

5. The method of claim 4, wherein step (IV) further comprises completely releasing at least one of the sub-sheets from the carrier glass while maintaining the curvature.

6. The method of claim 4, wherein step (IV) comprises producing a double bend curvature in the second major surface of the glass sheet by lifting an edge portion of one of the plurality of sub-sheets away from the carrier glass.

7. The method of claim 1, further comprising:

(IV) providing a second defect in the carrier substrate; and

(V) separating the carrier substrate into a plurality of sub-carrier substrates by traversing a beam of electromagnetic radiation relative to the carrier substrate along a second predetermined path.

8. The method of claim 7, wherein the first predetermined path is aligned with the second predetermined path.

9. The method of claim 7, wherein traversing the laser beam in step (V) produces a scribe line in the carrier substrate along the second predetermined path.

10. The method of claim 9, wherein step (V) further applies a bending force to the carrier substrate to separate the carrier substrate along the scribe line into the plurality of sub-carrier substrates.

11. The method of claim 7, wherein traversing the electromagnetic radiation during step (V) transforms the second defect into a second full body crack extending through the carrier substrate and propagates the second crack along the second predetermined path

produces a full body separation of the carrier substrate along the second predetermined path.

12. The method of claim 7, wherein each sub-carrier substrate provided by step (V) is bonded with a single corresponding one of the plurality of sub-sheets.

13. The method of claim 12, further comprising the step (VI) of releasing one of the sub-sheets from the corresponding sub-carrier substrate.

14. A method of separating a glass sheet comprising:

(I) providing a glass sheet including a first major surface, a second major surface opposing the first major surface, and a thickness between the first major surface and the second major surface equal to or less than about 300 μm, wherein the second major surface of the glass sheet is bonded to a support surface of a carrier substrate;

(II) providing a first defect in the glass sheet;

(III) separating the glass sheet into a plurality of sub-sheets by traversing a beam of electromagnetic radiation over the first major surface along a first predetermined path to:

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

(b) propagate the first full body crack along the first predetermined path, thereby producing a full body separation of the glass sheet along the first predetermined path while the second major surface of the glass sheet remains bonded to the support surface of the carrier substrate; and

(IV) releasing at least a portion of at least one sub-sheet from the carrier substrate by producing a curvature in at least one of the second major surface of the glass sheet and the support surface of the carrier substrate.

15. The method of claim 14, wherein step (IV) further comprises completely releasing at least one of the sub-sheets from the carrier glass while maintaining the curvature.

16. The method of claim 14, wherein step (IV) comprises producing a double bend curvature in the second major surface of the glass sheet by lifting an edge portion of one of the plurality of sub-sheets away from the carrier glass.

17. The method of claim 14, wherein step (IV) translates at least a pair of facing edge surfaces of an adjacent pair of sub-sheets away from one another along a direction of the first major surface to create a lateral gap between the pair of facing edge surfaces.

18. The method of claim 14, wherein step (II) further comprises providing a second defect in the glass sheet, and step (III) of separating the glass sheet into a plurality of sub-sheets further comprises traversing a beam of electromagnetic radiation over the first major surface along a second predetermined path to: (a) transform the second defect into a second full body crack intersecting the first major surface and the second major surface of the glass sheet; and (b) propagate the second full body crack along the second predetermined path, thereby producing a full body separation of the glass sheet along the second predetermined path while the second major surface of the glass sheet remains bonded to the support surface of the carrier substrate.

19. The method of claim 18, wherein the second predetermined path intersects the first predetermined path.

20. The method of claim 14, wherein step (I) includes the step of bonding the second major surface of the glass sheet to the support surface of the carrier substrate with a layer of adhesive material.

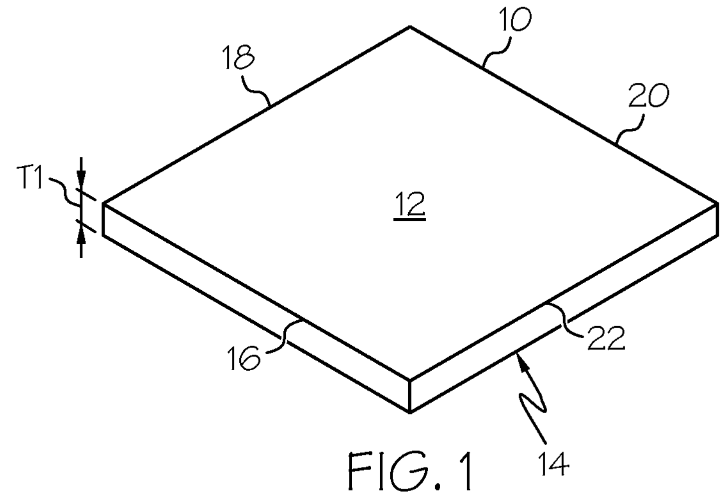


FIG. 1

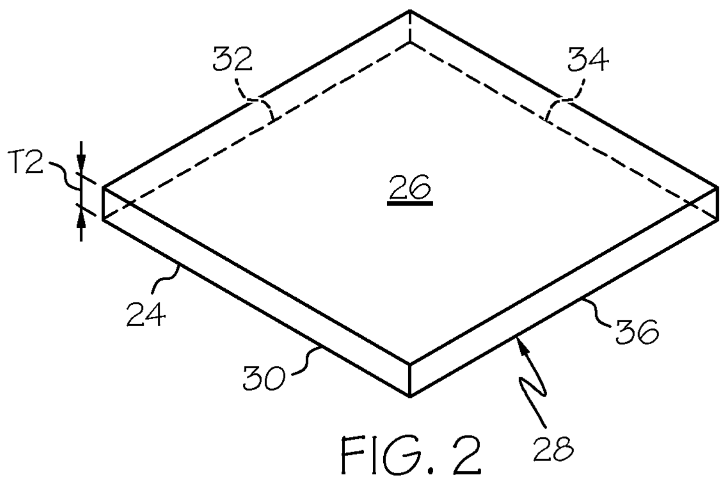


FIG. 2

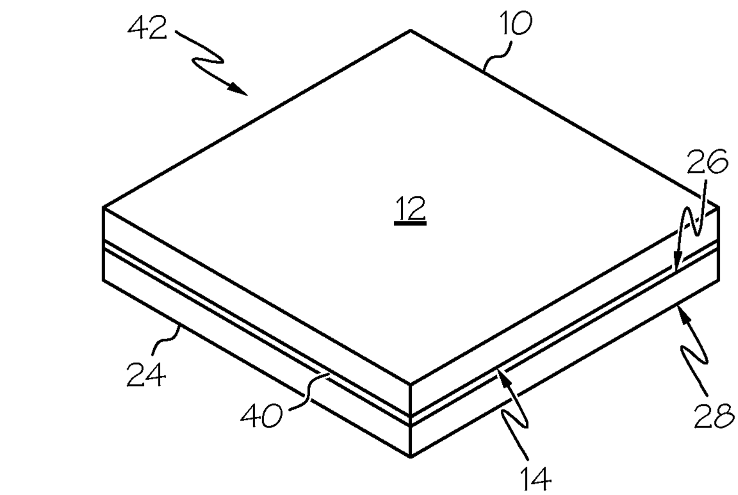


FIG. 3

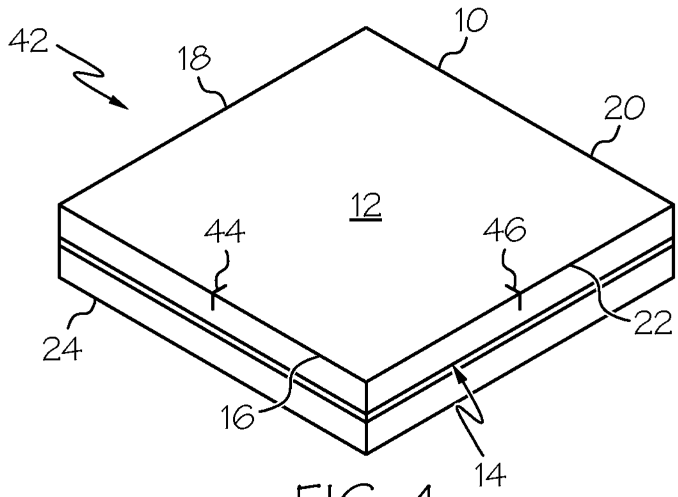


FIG. 4

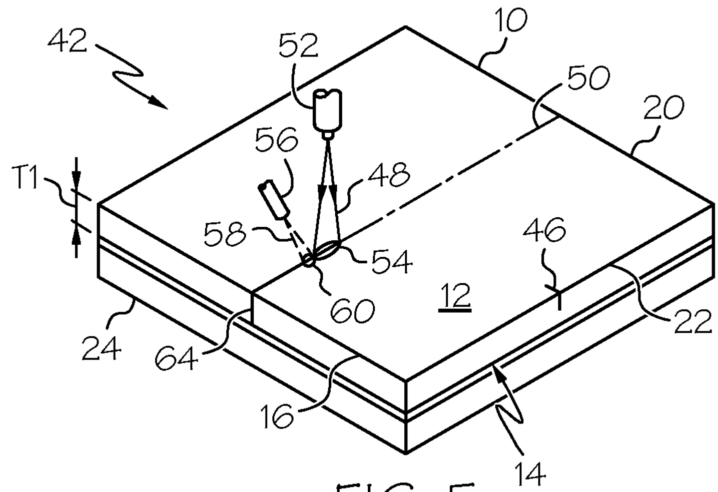


FIG. 5

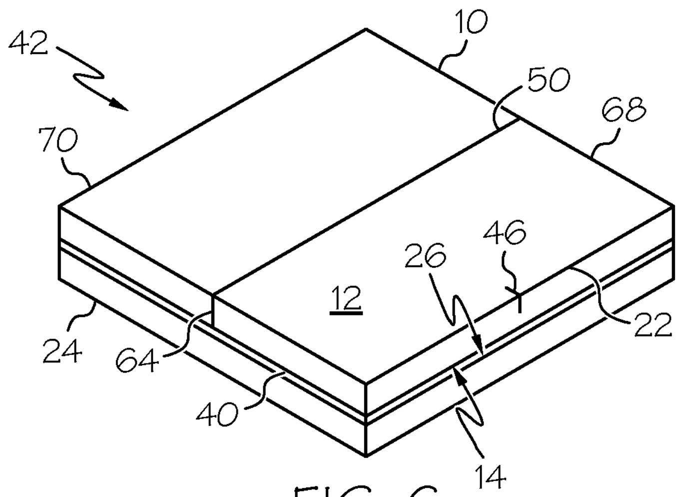


FIG. 6

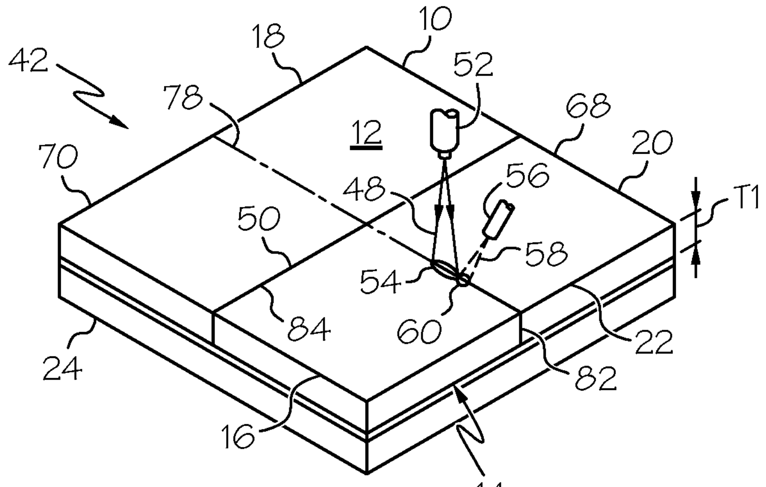


FIG. 7

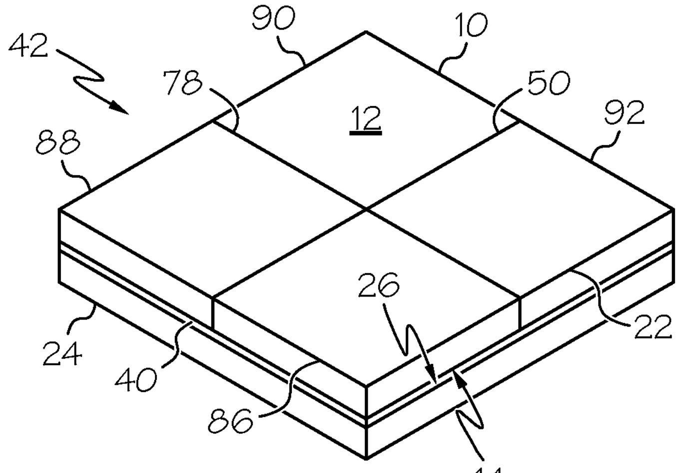


FIG. 8

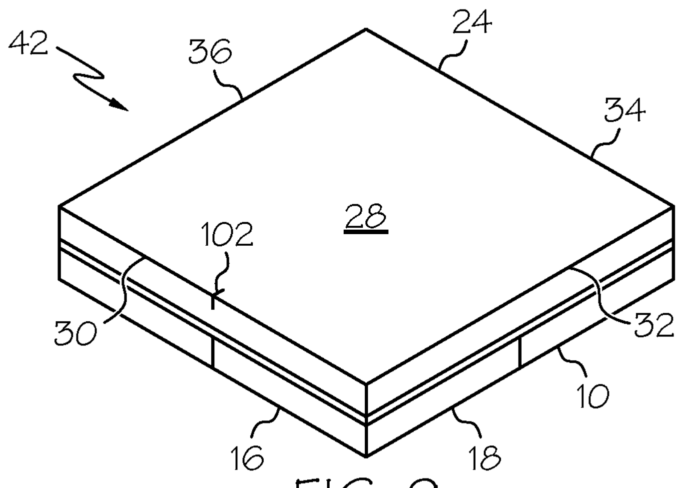


FIG. 9

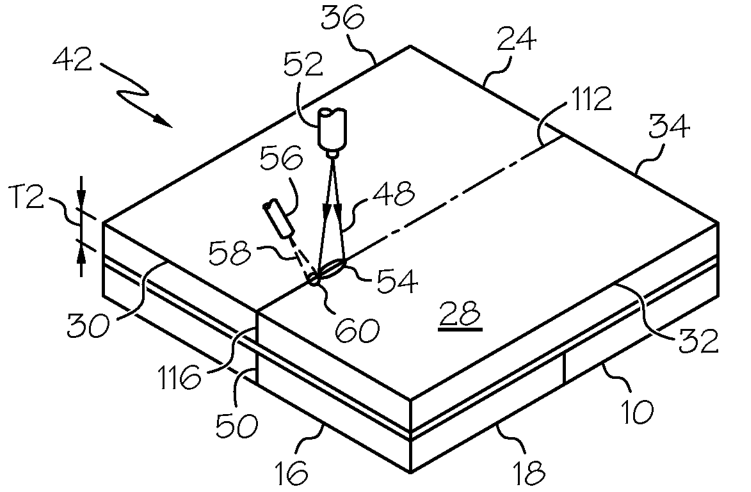
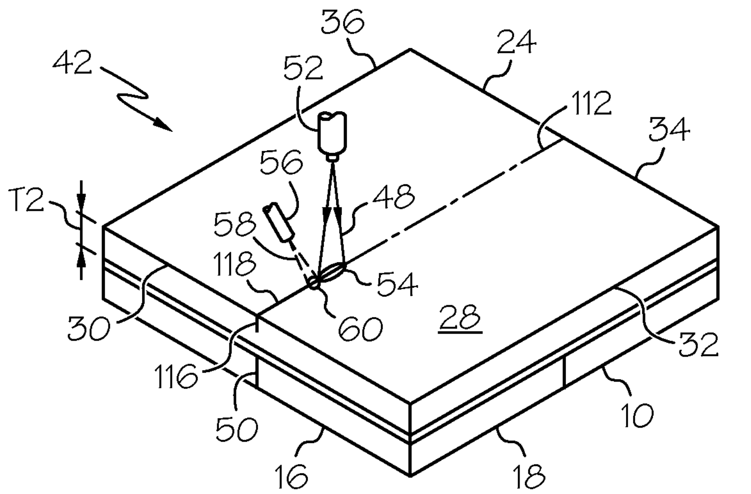

36
24
42
52
112
34
56
48
T2
58
54
28
30
60
32
116
50
10
16
18

FIG. 10


36
24
42
52
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48
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118
54
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30
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32
116
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16
18

FIG. 11

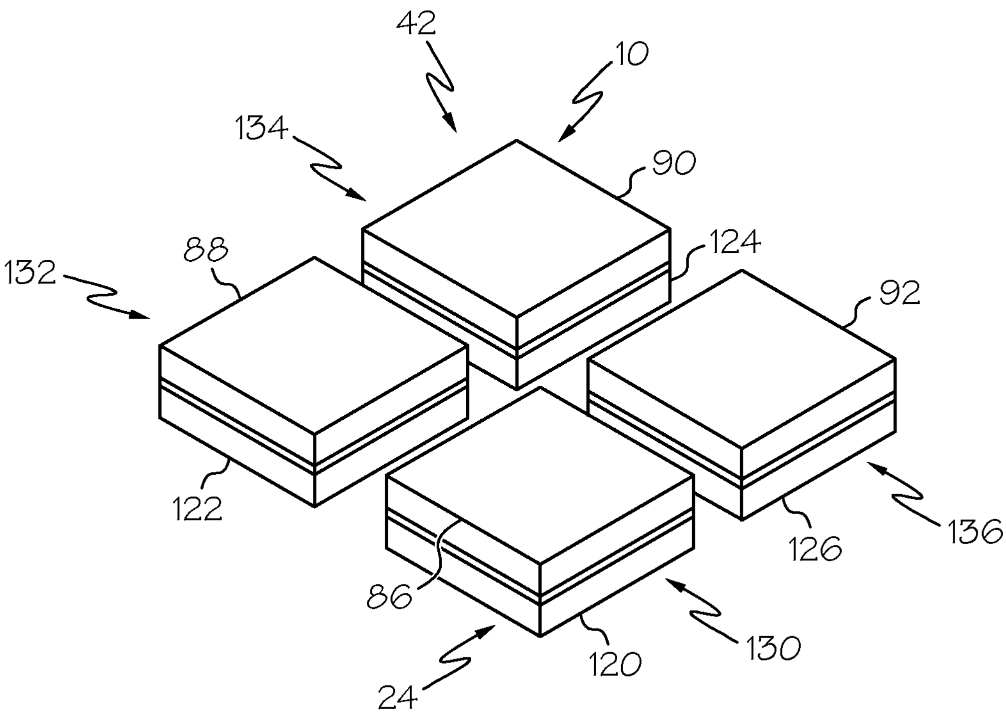

FIG. 12

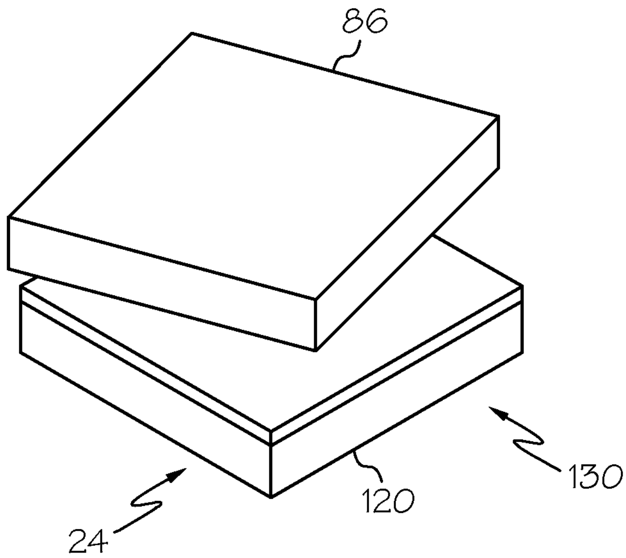

FIG. 13

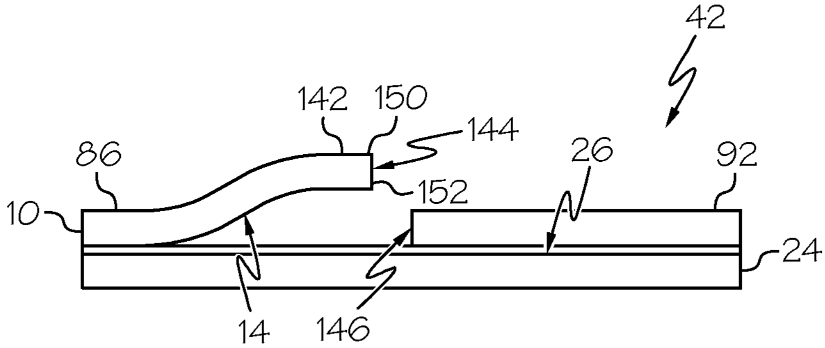

FIG. 14

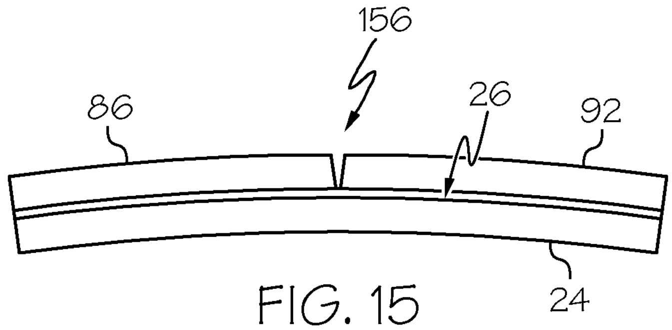

FIG. 15

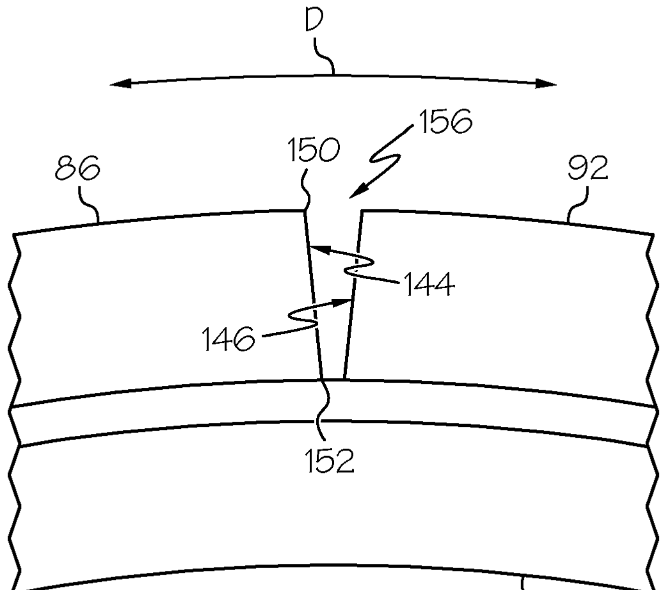

FIG. 16

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/039653

A. CLASSIFICATION OF SUBJECT MATTER
INV. C03B33/02 C03B33/03 C03B33/09
ADD. C03B33/04

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

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 2013/119737 A2 (CORNING INC [US]; ABRAMOV ANATOLI ANATOLYEVICH [US]; BELLMAN ROBERT AL) 15 August 2013 (2013-08-15) the whole document	1-20
X	US 2010/080989 A1 (ASAI FUMITERU [JP] ET AL) 1 April 2010 (2010-04-01) paragraphs [0014], [0018], [0019], [0044], [0045], [0051], [0072], [0078] - [0081], [0091]; figure 1	1-20
X	WO 2014/077397 A1 (IHI CORP [JP]) 22 May 2014 (2014-05-22) paragraph [0109]	1-20
X	WO 01/85387 A1 (PTG PREC TECHNOLOGY CT LTD LLC [US]) 15 November 2001 (2001-11-15) page 12, line 10 - line 31	1-20

-/--

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 October 2015	14/10/2015

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	Marrec, Patrick

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/068737 A1 (SAITO ISAO [JP]) 21 March 2013 (2013-03-21) paragraph [0028]; figures 1,3 -----	1-20
X	JP 2008 115067 A (LEMI LTD) 22 May 2008 (2008-05-22) abstract; figures 5,6 -----	1-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2015/039653

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