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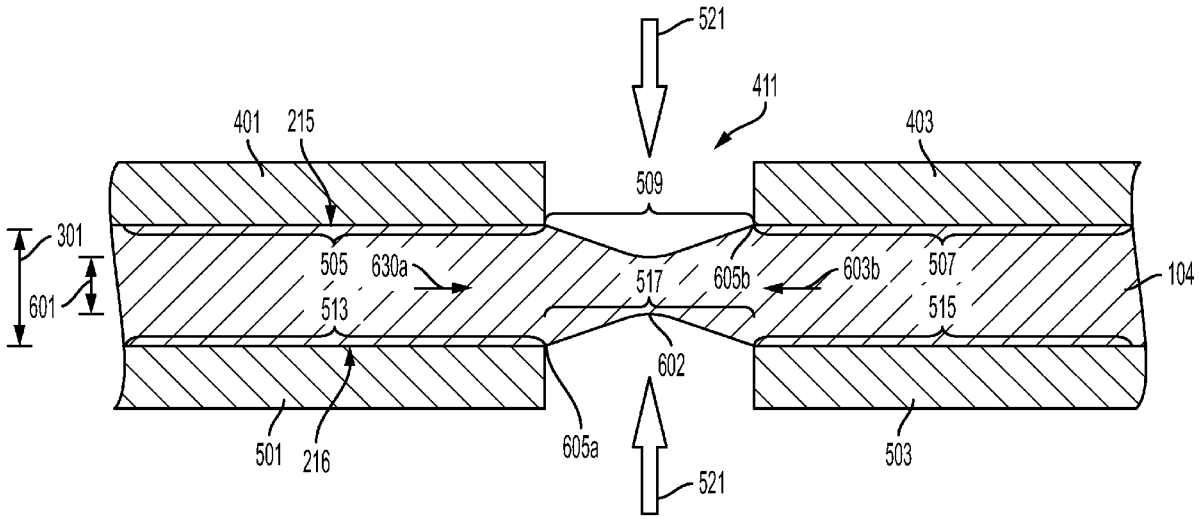

FIG. 6

(57) Abstract: A glass ribbon includes a first major surface extending along a first plane. The glass ribbon includes a second major surface extending along a second plane substantially parallel to the first plane. A first thickness is defined between the first major surface and the second major surface along a thickness direction perpendicular to the first major surface. The first thickness is within a range from about 25 μm to about 125 μm. An edge surface extends between the first plane and the second plane. The edge surface comprises a height in the thickness direction that is less than the first thickness. Methods of manufacturing a glass ribbon are also provided.

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METHODS AND APPARATUS FOR MANUFACTURING A GLASS RIBBON

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 62/864145 filed on June 20, 2019, the content of which is relied upon and incorporated herein by reference in its entirety.

FIELD

[0002] The present disclosure relates generally to methods for manufacturing a glass ribbon and, more particularly, to methods for manufacturing a glass ribbon with a tapered edge.

BACKGROUND

[0003] Known glass ribbons can comprise a thickness from about 20 micrometers (μm or microns) to about 200 μm. Forming these glass ribbons with an edge shape can be a slow and costly process. For example, the glass ribbon may initially comprise a larger than targeted thickness. The glass ribbon may then be cut into smaller portions, stacked to process the edges and/or form other cut-out shapes in the portions, and then separated and etched to a final, target thickness. However, such a process leads to increased surface roughness and reduced optical quality. An alternative approach involves utilizing a glass ribbon that is initially at a target thickness. However, to maintain this target thickness, one or more surfaces of the glass ribbon are shielded during processing (possibly including during any stacking), which is a challenging and costly process.

SUMMARY

[0004] There are set forth methods of manufacturing a glass ribbon, comprising masking a first region and a second region of a first major surface of the glass ribbon, such that the first major surface comprises a first exposed region between the first region and the second region. Methods comprise etching the first exposed region to separate a first ribbon portion from a second ribbon portion, and form a first tapered edge at the first ribbon portion and a second tapered edge at the second ribbon portion. By masking and etching the glass ribbon, one or more ribbon

portions can be formed at a target thickness with a tapered edge shape. The glass ribbon can initially be at a target thickness or may be at a larger than target thickness. The glass ribbon may be separable into smaller ribbon portions with a tapered edge shape and a target thickness. Such a glass ribbon comprises a thickness range from about 20 μm to about 200 μm. The tapered edge of the glass ribbon can reduce a maximum stress that the glass ribbon experiences during bending.

[0005] Embodiment 1. A method of manufacturing a glass ribbon comprises masking a first region and a second region of a first major surface of the glass ribbon, such that the first major surface comprises a first exposed region between the first region and the second region. The method comprises masking a third region and a fourth region of a second major surface of the glass ribbon, such that the second major surface comprises a second exposed region between the third region and the fourth region. The method comprises etching the first exposed region and the second exposed region to separate a first ribbon portion, comprising the first region and the third region, from a second ribbon portion, comprising the second region and the fourth region, and form a first tapered edge at the first ribbon portion and a second tapered edge at the second ribbon portion.

[0006] Embodiment 2. The method of embodiment 1, further comprising forming, prior to etching, an initial groove at the first exposed region.

[0007] Embodiment 3. The method of embodiment 2, wherein the forming the initial groove comprises perforating the first exposed region at a plurality of locations.

[0008] Embodiment 4. The method of embodiment 2, wherein the forming the initial groove comprises scoring the first exposed region.

[0009] Embodiment 5. The method of any one of embodiments 1-4, wherein the etching the first exposed region and the second exposed region comprises exposing the first exposed region and the second exposed region to an etchant for a period of time until the first ribbon portion is separated from the second ribbon portion and a gap is formed between the first tapered edge of the first ribbon portion and the second tapered edge of the second ribbon portion.

[0010] Embodiment 6. The method of any one of embodiments 1-4, wherein the etching the first exposed region and the second exposed region comprises exposing the first exposed region and the second exposed region to an etchant and concluding an exposure of the first exposed region and the second exposed region to the etchant prior to the first ribbon portion separating from the second ribbon portion.

[0011] Embodiment 7. The method of embodiment 6, further comprising applying a mechanical force to the glass ribbon to separate the first ribbon portion from the second ribbon portion after concluding the exposure of the first exposed region and the second exposed region to the etchant.

[0012] Embodiment 8. The method of embodiment 7, wherein the etching the first exposed region and the second exposed region comprises, following a separation of the first ribbon portion from the second ribbon portion, exposing the first tapered edge and the second tapered edge to a second etchant.

[0013] Embodiment 9. A method of manufacturing a glass ribbon comprises forming an initial groove at one or more of a first major surface of the glass ribbon or a second major surface of the glass ribbon, the initial groove formed between a first ribbon portion of the glass ribbon and a second ribbon portion of the glass ribbon. The method comprises etching the glass ribbon to reduce a thickness of the glass ribbon and separate the first ribbon portion from the second ribbon portion along the initial groove such that a first tapered edge is formed at the first ribbon portion and a second tapered edge is formed at the second ribbon portion.

[0014] Embodiment 10. The method of embodiment 9, wherein the forming the initial groove comprises perforating the first major surface at a plurality of locations between the first ribbon portion and the second ribbon portion.

[0015] Embodiment 11. The method of embodiment 9, wherein the forming the initial groove comprises scoring the first major surface between the first ribbon portion and the second ribbon portion.

[0016] Embodiment 12. The method of any one of embodiments 9-11, wherein the etching the glass ribbon comprises exposing the first major surface and the second major surface to an etchant for a period of time until the first ribbon portion is separated from the second ribbon portion and a gap is formed between the first tapered edge of the first ribbon portion and the second tapered edge of the second ribbon portion.

[0017] Embodiment 13. The method of any one of embodiments 9-11, wherein the etching the glass ribbon comprises exposing the first major surface and the second major surface to an etchant and concluding an exposure of the first major surface and the second major surface to the etchant prior to the first ribbon portion separating from the second ribbon portion.

[0018] Embodiment 14. The method of embodiment 13, further comprising applying a mechanical force to the glass ribbon to separate the first ribbon portion from the second ribbon portion after concluding the exposure of the first major surface and the second major surface to the etchant.

[0019] Embodiment 15. A method of manufacturing a glass ribbon comprises masking a first major surface and a second major surface of the glass ribbon. The method comprises unmasking a first exposed region of the first major surface and a second exposed region of the second major surface. The method comprises forming an initial groove at one or more of the first exposed region or the second exposed region, the initial groove formed between a first ribbon portion of the glass ribbon and a second ribbon portion of the glass ribbon. The method comprises etching the first exposed region and the second exposed region to separate the first ribbon portion from the second ribbon portion along the initial groove and form a first tapered edge at the first ribbon portion and a second tapered edge at the second ribbon portion.

[0020] Embodiment 16. The method of embodiment 15, wherein the unmasking the first exposed region and the second exposed region comprises directing a laser beam towards a mask covering the first exposed region and a second mask covering the second exposed region.

[0021] Embodiment 17. The method of embodiment 16, wherein the forming the initial groove comprises directing the laser beam towards the first exposed region to perforate the first exposed region at a plurality of locations.

[0022] Embodiment 18. The method of embodiment 16, wherein the forming the initial groove comprises scoring the first exposed region.

[0023] Embodiment 19. The method of any one of embodiments 15-18, further comprising maintaining an initial thickness of the glass ribbon such that the initial thickness of the glass ribbon, defined between the first major surface and the second major surface at a first location spaced a distance apart from the first exposed region and the second exposed region, prior to etching is substantially equal to a final thickness of the first ribbon portion, defined between the first major surface and the second major surface at the first location, after etching.

[0024] Embodiment 20. The method of embodiment 19, wherein the maintaining the initial thickness of the glass ribbon comprises maintaining the initial thickness within a range from about 20 μm to about 200 μm.

[0025] Embodiment 21. A glass ribbon comprises a first major surface extending along a first plane. The glass ribbon comprises a second major surface extending along a second plane substantially parallel to the first plane. A first thickness is defined between the first major surface and the second major surface along a thickness direction perpendicular to the first major surface. The first thickness is within a range from about 25 μm to about 125 μm. The glass ribbon comprises an edge surface extending between the first plane and the second plane. The edge surface comprises a height in the thickness direction that is less than the first thickness.

[0026] Embodiment 22. The glass ribbon of embodiment 21, wherein the edge surface extends along an edge plane that is substantially perpendicular to the first plane, the edge surface spaced a first separating thickness from the first plane and a second separating thickness from the second plane.

[0027] Embodiment 23. The glass ribbon of embodiment 22, wherein the first separating thickness is substantially equal to the second separating thickness.

[0028] Embodiment 24. The glass ribbon of embodiment 21, wherein the edge surface is non-planar.

[0029] Embodiment 25. A glass ribbon comprises a first major surface extending along a first plane and a second major surface extending along a second plane substantially parallel to the first plane. A first thickness is defined between the first major surface and the second major surface along a thickness direction perpendicular to the first major surface. The first thickness is within a range from about 25 μm to about 125 μm. The glass ribbon comprises an edge surface extending between the first plane and the second plane along an edge plane that is substantially perpendicular to the first plane. The glass ribbon comprises a first intermediate surface extending between a first outer edge of the first major surface and a first outer edge of the edge surface. The glass ribbon comprises a second intermediate surface extending between a first outer edge of the second major surface and a second outer edge of the edge surface. A first separating length between the first outer edge of the first major surface and the edge plane in a direction parallel to the first major surface is within a range from about 5 μm to about 85 μm and a first separating thickness between the first outer edge of the edge surface and the first plane along a direction parallel to the edge plane is within a range from about 25 μm to about 100 μm.

[0030] Embodiment 26. The glass ribbon of embodiment 25, wherein a second separating length between the first outer edge of the second major surface and the edge plane in a direction parallel to the second major surface is within a range from about 5 μm to about 85 μm.

[0031] Embodiment 27. The glass ribbon of embodiment 26, wherein the first separating length is substantially equal to the second separating length.

[0032] Embodiment 28. The glass ribbon of any one of embodiments 25-27, wherein a second separating thickness between the second outer edge of the edge surface and the second plane along the direction parallel to the edge plane is within a range from about 25 μm to about 100 μm.

[0033] Embodiment 29. The glass ribbon of embodiment 28, wherein the first separating thickness is substantially equal to the second separating thickness.

[0034] Embodiment 30. The glass ribbon of any one of embodiments 25-29, wherein the first intermediate surface is non-parallel with the second intermediate surface.

[0035] Embodiment 31. The glass ribbon of any one of embodiments 25-30, wherein the edge surface comprises a height in the thickness direction that is less than the first thickness.

[0036] Additional features and advantages of the embodiments disclosed herein will be set forth in the detailed description that follows, and in part will be clear to those skilled in the art from that description or recognized by practicing the embodiments described herein, including the detailed description which follows, the claims, as well as the appended drawings. It is to be understood that both the foregoing general description and the following detailed description present embodiments intended to provide an overview or framework for understanding the nature and character of the embodiments disclosed herein. The accompanying drawings are included to provide further understanding, and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments of the disclosure, and together with the description explain the principles and operations thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0037] These and other features, embodiments and advantages are better understood when the following detailed description is read with reference to the accompanying drawings, in which:

[0038] FIG. 1 schematically illustrates example embodiments of a glass manufacturing apparatus in accordance with embodiments of the disclosure;

[0039] FIG. 2 illustrates a perspective cross-sectional view of the glass manufacturing apparatus along line **2-2** of **FIG. 1** in accordance with embodiments of the disclosure;

[0040] FIG. 3 illustrates a perspective view of example embodiments of a glass ribbon in accordance with embodiments of the disclosure;

[0041] FIG. 4 illustrates a top view of example embodiments of a glass ribbon along line **4-4** of **FIG. 3** in accordance with embodiments of the disclosure;

[0042] FIG. 5 illustrates a sectional view of example embodiments of a glass ribbon along line **5-5** of **FIG. 4** in accordance with embodiments of the disclosure;

[0043] FIG. 6 illustrates a sectional view of example embodiments of a glass ribbon with an unmasked area of the glass ribbon exposed to an etchant in accordance with embodiments of the disclosure;

[0044] FIG. 7 illustrates a sectional view of example embodiments of a glass ribbon with a ribbon portion of the glass ribbon comprising a tapered edge in accordance with embodiments of the disclosure;

[0045] FIG. 8 illustrates a top view of example embodiments of a glass ribbon comprising an initial groove in accordance with embodiments of the disclosure

[0046] FIG. 9 illustrates a sectional view of example embodiments of a glass ribbon along line **9-9** of **FIG. 8** in accordance with embodiments of the disclosure;

[0047] FIG. 10 illustrates a sectional view of example embodiments of a glass ribbon with an unmasked area of the glass ribbon exposed to an etchant in accordance with embodiments of the disclosure;

[0048] FIG. 11 illustrates a sectional view of example embodiments of a glass ribbon after exposure of an unmasked area of the glass ribbon to an etchant has concluded in accordance with embodiments of the disclosure;

[0049] FIG. 12 illustrates a sectional view of example embodiments of a glass ribbon after separating a first ribbon portion from a second ribbon portion in accordance with embodiments of the disclosure;

[0050] FIG. 13 illustrates a sectional view of example embodiments of a glass ribbon in which a tapered edge of a ribbon portion is exposed to an etchant in accordance with embodiments of the disclosure;

[0051] FIG. 14 illustrates a top view of example embodiments of a glass ribbon in which a mask covers a first major surface of the glass ribbon in accordance with embodiments of the disclosure

[0052] FIG. 15 illustrates a sectional view of example embodiments of a glass ribbon along line **14-14** of **FIG. 14** in accordance with embodiments of the disclosure;

[0053] FIG. 16 illustrates a sectional view of example embodiments of a glass ribbon after removing a portion of a mask covering a major surface of the glass ribbon in accordance with embodiments of the disclosure;

[0054] FIG. 17 illustrates a sectional view of example embodiments of a glass ribbon in which an initial groove is formed in accordance with embodiments of the disclosure;

[0055] FIG. 18 illustrates an enlarged view of portions of a glass ribbon taken at view **18** of **FIG. 14** in accordance with embodiments of the disclosure;

[0056] FIG. 19 illustrates a top view of example embodiments of a glass ribbon in which an initial groove is formed in a first major surface of the glass ribbon in accordance with embodiments of the disclosure;

[0057] FIG. 20 illustrates a sectional view of example embodiments of a glass ribbon along line **20-20** of **FIG. 19** in accordance with embodiments of the disclosure;

[0058] FIG. 21 illustrates a sectional view of example embodiments of a glass ribbon exposed to an etchant in accordance with embodiments of the disclosure;

[0059] FIG. 22 illustrates a sectional view of example embodiments of a glass ribbon after exposure of the glass ribbon to an etchant has concluded in accordance with embodiments of the disclosure;

[0060] FIG. 23 illustrates a sectional view of example embodiments of a glass ribbon after separating a first ribbon portion from a second ribbon portion in accordance with embodiments of the disclosure;

[0061] FIG. 24 illustrates a sectional view of example embodiments of a glass ribbon after etching the glass ribbon to separate a first ribbon portion from a second ribbon portion in accordance with embodiments of the disclosure;

[0062] FIG. 25 illustrates a sectional view of example embodiments of a tapered edge of a glass ribbon in accordance with embodiments of the disclosure;

[0063] FIG. 26 illustrates a sectional view of additional embodiments of a tapered edge of a glass ribbon in accordance with embodiments of the disclosure;

[0064] FIG. 27 illustrates a perspective view of example embodiments of a glass ribbon subject to a bending test in accordance with embodiments of the disclosure;

[0065] FIG. 28 illustrates a sectional view of example embodiments of a glass ribbon along line **28-28** of **FIG. 27** in accordance with embodiments of the disclosure;

[0066] FIG. 29 illustrates a plot of some embodiments of a stress of a glass ribbon with a non-tapered edge in accordance with embodiments of the disclosure;

[0067] FIG. 30 illustrates a plot of some embodiments of a stress of a glass ribbon with a non-tapered edge in accordance with embodiments of the disclosure;

[0068] FIG. 31 illustrates a plot of some embodiments of a stress of a glass ribbon with a non-tapered edge in accordance with embodiments of the disclosure;

[0069] FIG. 32 illustrates a plot of some embodiments of a stress of a glass ribbon with a tapered edge in accordance with embodiments of the disclosure;

[0070] FIG. 33 illustrates an enlarged view of some embodiments of a tapered edge of a glass ribbon taken at view **33** of **FIG. 28** in accordance with embodiments of the disclosure;

[0071] FIG. 34 illustrates a plot of some embodiments of a stress of a glass ribbon with a tapered edge in accordance with embodiments of the disclosure; and

[0072] FIG. 35 illustrates an enlarged view of some embodiments of a tapered edge of a glass ribbon taken at view **33** of **FIG. 28** in accordance with embodiments of the disclosure.

DETAILED DESCRIPTION

[0073] Embodiments will now be described more fully hereinafter with reference to the accompanying drawings in which example embodiments are shown. Whenever possible, the same reference numerals are used throughout the drawings to refer to the same or like parts. However, this disclosure may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein.

[0074] The present disclosure relates to glass manufacturing apparatus and methods for manufacturing glass. Methods and apparatus for manufacturing glass will now be described by way of example embodiments for manufacturing a glass

ribbon from a quantity of molten material. As schematically illustrated in **FIG. 1**, in some embodiments, an exemplary glass manufacturing apparatus **100** can comprise a glass melting and delivery apparatus **102** and a forming apparatus **101** comprising a forming vessel **140** designed to produce a ribbon **103** from a quantity of molten material **121**. In some embodiments, the ribbon **103** can comprise a central portion **152** positioned between opposite edge portions (e.g., edge beads) formed along a first outer edge **153** and a second outer edge **155** of the ribbon **103**, wherein a thickness of the edge beads can be greater than a thickness of the central portion. Additionally, in some embodiments, a separated glass ribbon **104** can be separated from the ribbon **103** along a separation path **151** by a glass separator **149** (e.g., scribe, score wheel, diamond tip, laser, etc.). In some embodiments, before or after separation of the separated glass ribbon **104** from the ribbon **103**, the edge beads formed along the first outer edge **153** and the second outer edge **155** can be removed to provide the central portion **152** as a high-quality separated glass ribbon **104** comprising a uniform thickness.

[0075] In some embodiments, the glass melting and delivery apparatus **102** can comprise a melting vessel **105** oriented to receive batch material **107** from a storage bin **109**. The batch material **107** can be introduced by a batch delivery device **111** powered by a motor **113**. In some embodiments, an optional controller **115** can be operated to activate the motor **113** to introduce a desired amount of batch material **107** into the melting vessel **105**, as indicated by arrow **117**. The melting vessel **105** can heat the batch material **107** to provide molten material **121**. In some embodiments, a melt probe **119** can be employed to measure a level of molten material **121** within a standpipe **123** and communicate the measured information to the controller **115** by way of a communication line **125**.

[0076] Additionally, in some embodiments, the glass melting and delivery apparatus **102** can comprise a first conditioning station comprising a fining vessel **127** located downstream from the melting vessel **105** and coupled to the melting vessel **105** by way of a first connecting conduit **129**. In some embodiments, molten material **121** can be gravity fed from the melting vessel **105** to the fining vessel **127** by way of the first connecting conduit **129**. For example, in some embodiments, gravity can drive the molten material **121** through an interior pathway of the first connecting conduit **129** from the melting vessel **105** to the fining vessel **127**. Additionally, in

some embodiments, bubbles can be removed from the molten material **121** within the fining vessel **127** by various techniques.

[0077] In some embodiments, the glass melting and delivery apparatus **102** can further comprise a second conditioning station comprising a mixing chamber **131** that can be located downstream from the fining vessel **127**. The mixing chamber **131** can be employed to provide a homogenous composition of molten material **121**, thereby reducing or eliminating inhomogeneity that may otherwise exist within the molten material **121** exiting the fining vessel **127**. As shown, the fining vessel **127** can be coupled to the mixing chamber **131** by way of a second connecting conduit **135**. In some embodiments, molten material **121** can be gravity fed from the fining vessel **127** to the mixing chamber **131** by way of the second connecting conduit **135**. For example, in some embodiments, gravity can drive the molten material **121** through an interior pathway of the second connecting conduit **135** from the fining vessel **127** to the mixing chamber **131**.

[0078] Additionally, in some embodiments, the glass melting and delivery apparatus **102** can comprise a third conditioning station comprising a delivery vessel **133** that can be located downstream from the mixing chamber **131**. In some embodiments, the delivery vessel **133** can condition the molten material **121** to be fed into an inlet conduit **141**. For example, the delivery vessel **133** can function as an accumulator and/or flow controller to adjust and provide a consistent flow of molten material **121** to the inlet conduit **141**. As shown, the mixing chamber **131** can be coupled to the delivery vessel **133** by way of a third connecting conduit **137**. In some embodiments, molten material **121** can be gravity fed from the mixing chamber **131** to the delivery vessel **133** by way of the third connecting conduit **137**. For example, in some embodiments, gravity can drive the molten material **121** through an interior pathway of the third connecting conduit **137** from the mixing chamber **131** to the delivery vessel **133**. As further illustrated, in some embodiments, a delivery pipe **139** can be positioned to deliver molten material **121** to forming apparatus **101**, for example the inlet conduit **141** of the forming vessel **140**.

[0079] Forming apparatus **101** can comprise various embodiments of forming vessels in accordance with features of the disclosure comprising a forming vessel with a wedge for fusion drawing the glass ribbon, a forming vessel with a slot to slot draw the glass ribbon, or a forming vessel provided with press rolls to press roll the glass ribbon from the forming vessel. By way of illustration, the forming vessel **140** shown

and disclosed below can be provided to fusion draw molten material **121** off a bottom edge, defined as a root **145**, of a forming wedge **209** to produce a ribbon of molten material **121** that can be drawn into the ribbon **103**. For example, in some embodiments, the molten material **121** can be delivered from the inlet conduit **141** to the forming vessel **140**. The molten material **121** can then be formed into the ribbon **103** based, in part on the structure of the forming vessel **140**. For example, as shown, the molten material **121** can be drawn off the bottom edge (e.g., root **145)** of the forming vessel **140** along a draw path extending in a draw direction **154** of the glass manufacturing apparatus **100**. In some embodiments, edge directors **163**, **164** can direct the molten material **121** off the forming vessel **140** and define, in part, a width "**W**" of the ribbon **103**. In some embodiments, the width "**W**" of the ribbon **103** extends between the first outer edge **153** of the ribbon **103** and the second outer edge **155** of the ribbon **103**.

[0080] In some embodiments, the width "**W**" of the ribbon **103**, which extends between the first outer edge **153** of the ribbon **103** and the second outer edge **155** of the ribbon **103**, can be greater than or equal to about 20 millimeters (mm), for example, greater than or equal to about 50 mm, for example, greater than or equal to about 100 mm, for example, greater than or equal to about 500 mm, for example, greater than or equal to about 1000 mm, for example, greater than or equal to about 2000 mm, for example, greater than or equal to about 3000 mm, for example, greater than or equal to about 4000 mm, although other widths less than or greater than the widths mentioned above can be provided in further embodiments. For example, in some embodiments, the width "**W**" of the ribbon **103** can be within a range from about 20 mm to about 4000 mm, for example, within a range from about 50 mm to about 4000 mm, for example, within a range from about 100 mm to about 4000 mm, for example, within a range from about 500 mm to about 4000 mm, for example, within a range from about 1000 mm to about 4000 mm, for example, within a range from about 2000 mm to about 4000 mm, for example, within a range from about 3000 mm to about 4000 mm, for example, within a range from about 20 mm to about 3000 mm, for example, within a range from about 50 mm to about 3000 mm, for example, within a range from about 100 mm to about 3000 mm, for example, within a range from about 500 mm to about 3000 mm, for example, within a range from about 1000 mm to about 3000 mm, for example, within a range from about 2000 mm to about

3000 mm, for example, within a range from about 2000 mm to about 2500 mm, and all ranges and subranges therebetween.

[0081] FIG. 2 shows a cross-sectional perspective view of the forming apparatus **101** (e.g., forming vessel **140**) along line **2-2** of **FIG. 1**. In some embodiments, the forming vessel **140** can comprise a trough **201** oriented to receive the molten material **121** from the inlet conduit **141**. For illustrative purposes, cross-hatching of the molten material **121** is removed from **FIG. 2** for clarity. The forming vessel **140** can further comprise the forming wedge **209** comprising a pair of downwardly inclined converging surface portions **207**, **208** extending between opposed ends **210**, **211** (See **FIG. 1**) of the forming wedge **209**. The pair of downwardly inclined converging surface portions **207**, **208** of the forming wedge **209** can converge along the draw direction **154** to intersect along the root **145** of the forming vessel **140**. A draw plane **213** of the glass manufacturing apparatus **100** can extend through the root **145** along the draw direction **154**. In some embodiments, the ribbon **103** can be drawn in the draw direction **154** along the draw plane **213**. As shown, the draw plane **213** can bisect the forming wedge **209** through the root **145** although, in some embodiments, the draw plane **213** can extend at other orientations relative to the root **145**.

[0082] Additionally, in some embodiments, the molten material **121** can flow in a direction **156** into and along the trough **201** of the forming vessel **140**. The molten material **121** can then overflow from the trough **201** by simultaneously flowing over corresponding weirs **203**, **204** and downward over the outer surfaces **205**, **206** of the corresponding weirs **203**, **204**. Respective streams of molten material **121** can then flow along the downwardly inclined converging surface portions **207**, **208** of the forming wedge **209** to be drawn off the root **145** of the forming vessel **140**, where the flows converge and fuse into the ribbon **103**. The ribbon **103** of molten material can then be drawn off the root **145** in the draw plane **213** along the draw direction **154**. In some embodiments, the ribbon **103** comprises one or more states of material based on a vertical location of the ribbon **103**. For example, at one location, the ribbon **103** can comprise the viscous molten material **121**, and at another location, the ribbon **103** can comprise an amorphous solid in a glassy state (e.g., a glass ribbon).

[0083] The ribbon **103** comprises a first major surface **215** and a second major surface **216** facing opposite directions and defining a thickness "**T**" (e.g., average

thickness) of the ribbon **103**. In some embodiments, the thickness "**T**" of the ribbon **103** can be less than or equal to about 2 millimeters (mm), less than or equal to about 1 millimeter, less than or equal to about 0.5 millimeters, for example, less than or equal to about 300 micrometers (μm), less than or equal to about 200 micrometers, or less than or equal to about 100 micrometers, although other thicknesses may be provided in further embodiments. For example, in some embodiments, the thickness "**T**" of the ribbon **103** can be within a range from about 20 μm to about 200 μm, within a range from about 50 μm to about 750 μm, within a range from about 100 μm to about 700 μm, within a range from about 200 μm to about 600 μm, within a range from about 300 μm to about 500 μm, within a range from about 50 μm to about 500 μm, within a range from about 50 μm to about 700 μm, within a range from about 50 μm to about 600 μm, within a range from about 25 μm to about 500 μm, within a range from about 50 μm to about 400 μm, within a range from about 50 μm to about 300 μm, within a range from about 50 μm to about 200 μm, within a range from about 50 μm to about 100 μm, within a range from about 25 μm to about 125 μm, comprising all ranges and subranges of thicknesses therebetween. In addition, the ribbon **103** can comprise a variety of composition, for example, soda-lime glass, borosilicate glass, alumino-borosilicate glass, alkali-containing glass, or alkali-free glass, alkali aluminosilicate glass, alkaline earth aluminosilicate glass, etc.

[0084] In some embodiments, the glass separator **149** (see **FIG. 1**) can then separate the glass ribbon **104** from the ribbon **103** along the separation path **151** as the ribbon **103** is formed by the forming vessel **140**. As illustrated, in some embodiments, the separation path **151** can extend along the width "**W**" of the ribbon **103** between the first outer edge **153** and the second outer edge **155**. Additionally, in some embodiments, the separation path **151** can extend perpendicular to the draw direction **154** of the ribbon **103**. Moreover, in some embodiments, the draw direction **154** can define a direction along which the ribbon **103** can be drawn from the forming vessel **140**.

[0085] In some embodiments, a plurality of separated glass ribbons **104** can be stacked to form a stack of separated glass ribbons **104**. In some embodiments, interleaf material can be placed between an adjacent pair of separated glass ribbons **104** to help prevent contact and therefore preserve the pristine surfaces of the pair of separated glass ribbons **104**.

[0086] In further embodiments, although not shown, the ribbon **103** from the glass manufacturing apparatus may be coiled onto a storage roll. Once a desired length of coiled ribbon is stored on the storage roll, the ribbon **103** may be separated by the glass separator **149** such that the separated glass ribbon is stored on the storage roll. In further embodiments, a separated glass ribbon can be separated into another separated glass ribbon. For example, a separated glass ribbon **104** (e.g., from the stack of glass ribbons) can be further separated into another separated glass ribbon. In further embodiments, a separated glass ribbon stored on a storage roll can be uncoiled and further separated into another separated glass ribbon.

[0087] The separated glass ribbon can then be processed into a desired application, e.g., a display application. For example, the separated glass ribbon can be used in a wide range of display applications, comprising liquid crystal displays (LCDs), electrophoretic displays (EPD), organic light emitting diode displays (OLEDs), plasma display panels (PDPs), touch sensors, photovoltaics, and other electronic displays.

[0088] Referring to **FIG. 3**, a perspective view of the glass ribbon **104** is illustrated. The glass ribbon **104** can comprise the first major surface **215** and the second major surface **216**. In some embodiments, one or more of the first major surface **215** or the second major surface **216** may be planar. For example, the first major surface **215** and the second major surface **216** may be planar, and, in some embodiments, the first major surface **215** may be parallel to the second major surface **216**. An initial thickness **301** can be defined between the first major surface **215** and the second major surface **216** within a range from about 20 micrometers (μm) to about 200 μm or within a range from about 25 μm to about 125 μm. In some embodiments, the initial thickness **301** may be within a range from about 50 μm to about 100 μm. In some embodiments, the initial thickness **301** may be within a range from about 60 μm to about 80 μm. In some embodiments, the glass ribbon **104** can comprise an edge **303** extending between the first major surface **215** and the second major surface **216**. The edge **303** can be defined at an outermost perimeter of the glass ribbon **104**, and may extend about a border of the glass ribbon **104**.

[0089] In some embodiments, the glass ribbon **104** can comprise one or more of an alkali-free aluminosilicate, borosilicate, boroaluminosilicate, or silicate glass composition. In some embodiments, the glass ribbon **104** can comprise alkali-containing aluminosilicate, borosilicate, boroaluminosilicate, or silicate glass

compositions. In some embodiments, alkaline earth modifiers can be added to any of the foregoing compositions for the glass ribbon **104**. In some embodiments, the glass ribbon **104** can comprise one or more of the following glass compositions: SiO_2 within a range from about 64% to about 69% (by mol%, all percentages of compositional elements being given in mol% unless stated otherwise), Al_2O_3 within a range from about 5% to about 12%, B_2O_3 within a range from about 8% to about 23%, MgO within a range from about 0.5% to about 2.5%, CaO within a range from about 1% to about 9%, SrO within a range from about 0% to about 5%, BaO within a range from about 0% to about 5%, SnO_2 within a range from about 0.1% to about 0.4%, ZrO_2 within a range from about 0% to about 0.1%, or Na_2O within a range from about 1% to about 1%. In some embodiments, the glass ribbon **104** can comprise one or more of the following glass compositions: SiO_2 at about 67.4% (by mol%), Al_2O_3 at about 12.7%, B_2O_3 at about 3.7%, MgO at about 2.4%, CaO at about 0%, SrO at about 0%, SnO_2 at about 0.1%, or Na_2O at about 13.7%. In some embodiments, the glass ribbon **104** can comprise a lower elastic modulus to reduce a tensile stress during bending.

[0090] Referring to **FIG. 4**, a top view of the glass ribbon **104** is illustrated along line **4-4** of **FIG. 3**. In some embodiments, a portion of the glass ribbon **104** can be masked. For example, a first mask **401**, a second mask **403**, a third mask **405**, and/or a fourth mask **407** can be positioned to cover the first major surface **215**. In some embodiments, one or more unmasked areas may be defined between adjacent masks **401**, **403**, **405**, **407**. For example, a first unmasked area **411** may be defined between the first mask **401** and the second mask **403**. A second unmasked area **413** may be defined between the second mask **403** and the fourth mask **407**. A third unmasked area **415** may be defined between the third mask **405** and the fourth mask **407**. A fourth unmasked area **417** may be defined between the first mask **401** and the third mask **405**. In some embodiments, the unmasked areas **411**, **413**, **415**, **417** may be exposed and not covered by a mask. For example, an axis perpendicular to the first major surface **215** may not intersect one of the masks **401**, **403**, **405**, **407** at the first unmasked area **411**, the second unmasked area **413**, the third unmasked area **415**, and/or the fourth unmasked area **417**. While the glass ribbon **104** is illustrated as being masked by four masks in **FIG. 4**, the glass ribbon **104** is not so limited, and, in some embodiments, the glass ribbon **104** can be masked by zero or more masks. For example, in some embodiments, the glass ribbon **104** can be masked by the first mask

401 and the second mask **403**, but not the third mask **405** or the fourth mask **407**. In some embodiments, the glass ribbon **104** may initially be masked by a singled mask (e.g., as illustrated in **FIG. 14**), while in some embodiments, the glass ribbon **104** may initially be unmasked (e.g., as illustrated in **FIG. 19**).

[0091] Referring to **FIG. 5**, a sectional view of the glass ribbon **104** is illustrated along line **5-5** of **FIG. 4**. In some embodiments, in addition to the first major surface **215** being at least partially masked (e.g., as illustrated in **FIG. 4** with the first mask **401**, the second mask **403**, the third mask **405**, and the fourth mask **407**), the second major surface **216** can similarly be masked. In some embodiments, the second major surface **216** may be masked with the same number of masks of the first major surface **215**. In some embodiments, one or all of the masks of the first major surface **215** may be paired with a corresponding mask of the second major surface **216**. In some embodiments, the masks of each pair of masks may be laterally aligned along a direction perpendicular to the first major surface **215** and/or the second major surface **216**. In some embodiments, the masks of each pair of masks may each be the same shape and/or size. For example, methods of manufacturing the glass ribbon **104** can comprise masking the first major surface **215** and the second major surface **216** of the glass ribbon **104** with one or more masks. In some embodiments, a fifth mask **501** can mask the second major surface **216** substantially opposite the first mask **401** masking the first major surface **215**. In some embodiments, a shape, size, and lateral location of the first mask **401** can substantially match the fifth mask **501**. For example, the first mask **401** and the fifth mask **501** may be laterally aligned wherein an axis substantially perpendicular to a plane defined by the glass ribbon **104** can, at some locations, intersect the first mask **401** and the fifth mask **501**, and, at remaining locations, intersect none of the first mask **401** or the fifth mask **501**. In some embodiments, a sixth mask **503** can mask the second major surface **216** substantially opposite the second mask **403** masking the first major surface **215**. In some embodiments, a shape, size, and lateral location of the second mask **403** can substantially match the sixth mask **503**. For example, the second mask **403** and the sixth mask **503** may be laterally aligned wherein an axis substantially perpendicular to a plane defined by the glass ribbon **104** can, at some locations, intersect the second mask **403** and the sixth mask **503**, and, at remaining locations, intersect none of the second mask **403** or the sixth mask **503**. Though not illustrated in **FIG. 5**, in some embodiments, additional masks can mask the second major surface

216 at locations that are substantially opposite the third mask **405** (e.g., illustrated in **FIG. 4**) and the fourth mask **407** (e.g., illustrated in **FIG. 4**) that mask the first major surface **215**.

[0092] In some embodiments, methods of manufacturing the glass ribbon **104** can comprise masking a first region **505** and a second region **507** of the first major surface **215** of the glass ribbon **104**. For example, to mask the first region **505** and the second region **507**, the first mask **401** can be positioned to cover the first region **505** while the second mask **403** can be positioned to cover the second region **507**. In some embodiments, the first mask **401** and the second mask **403** can be positioned to cover the corresponding region in several ways, for example, by lamination, screen printing, etc. In some embodiments, the first mask **401** and the second mask **403** can comprise a material that may be resistant to an etchant to which the glass ribbon **104** may be exposed. For example, the first mask **401** and/or the second mask **403** can comprise one or more of a Vitayon HF resistant ink or other etch resistant type inks, a photolithography resist (e.g., AZP4620, etc.), a polystyrene material with a silane modification, a laminated film, etc. By masking the first region **505** and the second region **507**, a first exposed region **509** of the first major surface **215** may be exposed between the first region **505** and the second region **507**, wherein the first exposed region **509** may not be covered by a mask. In some embodiments, methods of manufacturing the glass ribbon **104** can comprise masking a third region **513** and a fourth region **515** of the second major surface **216** of the glass ribbon **104**. For example, to mask the third region **513** and the fourth region **515**, the fifth mask **501** can be positioned to cover the third region **513** while the sixth mask **503** can be positioned to cover the fourth region **515**. In some embodiments, the fifth mask **501** and the sixth mask **503** can be positioned to cover the corresponding region in several ways, for example, by lamination, screen printing, etc. In some embodiments, the fifth mask **501** and the sixth mask **503** can comprise a material that may be resistant to an etchant to which the glass ribbon **104** may be exposed. For example, the fifth mask **501** and/or the sixth mask **503** may comprise a similar material as the first mask **401** and the second mask **403**, for example, by comprising one or more of a Vitayon HF resistant ink or other etch resistant type inks, a photolithography resist (e.g., AZP4620, etc.), a polystyrene material with a silane modification, a laminated film, etc. By masking the third region **513** and the fourth region **515**, a second exposed region **517** of the second major surface **216** may be exposed between the third region

513 and the fourth region **515**, wherein the second exposed region **517** may not be covered by a mask. In some embodiments, the masks illustrated and described herein relative to **FIGS. 1-24** can comprise the same material, though, in some embodiments, the masks may comprise differing materials.

[0093] In some embodiments, methods of manufacturing the glass ribbon **104** can comprise etching the first exposed region **509** and the second exposed region **517** to separate a first ribbon portion, comprising the first region **505** and the third region **513**, from a second ribbon portion, comprising the second region **507** and the fourth region **515**. To etch the first exposed region **509** and the second exposed region **517**, the glass ribbon **104** can be exposed to an etchant **521**. For example, due to portions of the first major surface **215** and the second major surface **216** being masked (e.g., by the first mask **401**, the second mask **403**, the third mask **405**, the fourth mask **407**, the fifth mask **501**, the sixth mask **503**, etc.), the masked portions of the first major surface **215** and the second major surface **216** may be covered, sheltered, shielded, etc. In some embodiments, the masks **401**, **403**, **405**, **407**, **501**, **503**, can be resistant to the etchant **521** such that areas of the first major surface **215** and/or the second major surface **216** that may be covered by the masks **401**, **403**, **405**, **407**, **501**, **503** may not be etched. In some embodiments, the masks **401**, **403**, **405**, **407**, **501**, **503** can remain on the first major surface **215** or the second major surface **216** of the glass ribbon **104** during the etching. In some embodiments, the etchant **521** can comprise one or more of from about 0% to about 50% HF, a combination of HF and HNO_3, H_sSO_4, etc.

[0094] In some embodiments, methods of manufacturing the glass ribbon **104** can comprise maintaining the initial thickness **301** of the glass ribbon **104** such that the initial thickness **301** of the glass ribbon **104**, defined between the first major surface **215** and the second major surface **216** at a first location **525** spaced a distance **527** apart from the first exposed region **509** and the second exposed region **517**, prior to etching may be substantially equal to a final thickness (e.g., final thickness **751** illustrated in **FIG. 7**) of a first ribbon portion (e.g., first ribbon portion **701** illustrated in **FIG. 7**), defined between the first major surface **215** and the second major surface **216** at the first location **525**, after etching. For example, due to the masking of portions of the first major surface **215** and the second major surface **216**, the masked portions (e.g., the first region **505**, the second region **507**, the third region **513**, the fourth region **515**) may not be exposed to the etchant **521**, such that the initial

thickness **301** of the masked portions of the glass ribbon **104** can be maintained. In some embodiments, the initial thickness **301** can be maintained throughout the etching, for example, from the time that the glass ribbon **104** is initially exposed to the etchant **521** to the time that exposure of the glass ribbon **104** to the etchant **521** has concluded. In some embodiments, after the exposure of the glass ribbon **104** to the etchant **521** has concluded (e.g., illustrated in **FIG. 7**), the final thickness **751** of the masked portions of the glass ribbon **104** may be substantially equal to the initial thickness **301** of the masked portions of the glass ribbon **104**. In some embodiments, the maintaining the initial thickness **301** of the glass ribbon **104** can comprise maintain the initial thickness **301** that may be within a range from about 20 μm to about 200 μm or within a range from about 25 μm to about 125 μm. For example, the initial thickness **301**, may be within a range from about 20 μm to about 200 μm or within a range from about 25 μm to about 125 μm, can be maintained such that the final thickness **751** may likewise be within a range from about 20 μm to about 200 μm or within a range from about 25 μm to about 125 μm.

[0095] Referring to **FIG. 6**, the glass ribbon **104** is illustrated during the etching while the first unmasked area **411** (e.g., comprising the first exposed region **509** and the second exposed region **517**) is exposed to the etchant **521**. In some embodiments, the etchant **521** can reduce a thickness of the glass ribbon **104** at the first unmasked area **411**. For example, after exposing the first exposed region **509** and the second exposed region **517** to the etchant **521** for a period of time, a minimum thickness **601** of the glass ribbon **104** between the first exposed region **509** and the second exposed region **517** may be less than the initial thickness **301** of the glass ribbon **104** at areas that may be masked (e.g., between the first region **505** and the third region **513**, between the second region **507** and the fourth region **515**, etc.). In some embodiments, the minimum thickness **601** of the glass ribbon **104** may be located at an intermediate location **602** (e.g., midpoint) between the first mask **401** and the second mask **403**, and between the fifth mask **501** and the sixth mask **503**. For example, the glass ribbon **104** at the first unmasked area **411** may comprise an hour-glass shape, wherein the thickness of the glass ribbon **104** tapers in a first direction **603a** that extends away from a location **605a** adjacent the first region **505** and the third region **513** to the intermediate location **602** and wherein the thickness of the glass ribbon **104** tapers in a second direction **603b**, opposite the first direction

603a, that extends away from a location **605b** adjacent the second region **507** and the fourth region **515** to the intermediate location **602**.

[0096] Referring to **FIG. 7**, in some embodiments, methods of manufacturing the glass ribbon **104** can comprise etching the first exposed region **509** and the second exposed region **517** (e.g., illustrated in **FIGS. 5-6**) to separate a first ribbon portion **701**, comprising the first region **505** and the third region **513**, from a second ribbon portion **703**, comprising the second region **507** and the fourth region **515**, and form a first tapered edge **705** at the first ribbon portion **701** and a second tapered edge **707** at the second ribbon portion **703**. For example, the first exposed region **509** and the second exposed region **517** can be exposed to the etchant **521** such that the etching (e.g., illustrated in **FIGS. 5-6**) can continue until a gap **711** is formed in the first unmasked area **411**. When the gap **711** is formed, the first ribbon portion **701** (e.g., comprising the first region **505** and the third region **513** of the glass ribbon **104**) may be separated from the second ribbon portion **703** (e.g., comprising the second region **507** and the fourth region **515**). Once the gap **711** is formed, the etching may stop. In some embodiments, the etching the first exposed region **509** and the second exposed region **517** can comprise exposing the first exposed region **509** and the second exposed region **517** to the etchant **521** for a period of time until the first ribbon portion **701** is separated from the second ribbon portion **703**, and the gap **711** is formed between the first tapered edge **705** of the first ribbon portion **701** and the second tapered edge **707** of the second ribbon portion **703**. In some embodiments, the etching the glass ribbon **104** can comprise exposing the first major surface **215** and the second major surface **216** to the etchant **521** for a period of time until the first ribbon portion **701** is separated from the second ribbon portion **703** and the gap **711** is formed between the first tapered edge **705** of the first ribbon portion **701** and the second tapered edge **707** of the second ribbon portion **703**.

[0097] In some embodiments, the first tapered edge **705** can comprise a thickness that may be non-constant. For example, the first tapered edge **705** can comprise a thickness that decreases along a first axis **721**, which may be parallel to the first major surface **215** and the second major surface **216** of the first ribbon portion **701**, in the first direction **603a** from a center of the first ribbon portion **701** towards a perimeter of the first ribbon portion **701**. For example, the first tapered edge **705** can comprise a first intermediate surface **725** and a second intermediate surface **727**. The first intermediate surface **725** may be contiguous with the first

major surface **215** of the first ribbon portion **701**, while the second intermediate surface **727** may be contiguous with the second major surface **216** of the first ribbon portion **701**. In some embodiments, the first intermediate surface **725** may not be co-planar with the first major surface **215** of the first ribbon portion **701**, and may be non-parallel with the first major surface **215** of the first ribbon portion **701**. In some embodiments, the second intermediate surface **727** may not be co-planar with the second major surface **216** of the first ribbon portion **701**, and may be non-parallel with the second major surface **216** of the first ribbon portion **701**. In some embodiments, the first intermediate surface **725** and the second intermediate surface **727** may be non-parallel, for example, with the first intermediate surface **725** and the second intermediate surface **727** converging along the first axis **721** in the first direction **603a**. In some embodiments, the first intermediate surface **725** and the second intermediate surface **727** can converge to a point at a first outer boundary **729** of the first tapered edge **705**. In some embodiments, the first outer boundary **729** can comprise a rounded shape.

[0098] In some embodiments, the second tapered edge **707** can comprise a thickness that may be non-constant. For example, the second tapered edge **707** can comprise a thickness that decreases along a second axis **731**, which may be parallel to the first major surface **215** and the second major surface **216** of the second ribbon portion **703**, in the second direction **603b** from a center of the second ribbon portion **703** towards a perimeter of the second ribbon portion **703**. For example, the second tapered edge **707** can comprise a third intermediate surface **735** and a fourth intermediate surface **737**. The third intermediate surface **735** may be contiguous with the first major surface **215** of the second ribbon portion **703**, while the fourth intermediate surface **737** may be contiguous with the second major surface **216** of the second ribbon portion **703**. In some embodiments, the third intermediate surface **735** may not be co-planar with the first major surface **215** of the second ribbon portion **703**, and may be non-parallel with the first major surface **215** of the second ribbon portion **703**. In some embodiments, the fourth intermediate surface **737** may not be co-planar with the second major surface **216** of the second ribbon portion **703**, and may be non-parallel with the second major surface **216** of the second ribbon portion **703**. In some embodiments, the third intermediate surface **735** and the fourth intermediate surface **737** may be non-parallel, for example, with the third intermediate surface **735** and the fourth intermediate surface **737** converging along the second axis

731 in the second direction **603b**. In some embodiments, the third intermediate surface **735** and the fourth intermediate surface **737** can converge to a point at a second outer boundary **739** of the second tapered edge **707**. In some embodiments, the second outer boundary **739** can comprise a rounded shape.

[0099] Following the separation of the first ribbon portion **701** and the second ribbon portion **703**, the first ribbon portion **701** and the second ribbon portion **703** can be unmasked. For example, the first mask **401** and the fifth mask **501** can be removed from the first ribbon portion **701**, while the second mask **403** and the sixth mask **503** can be removed from the second ribbon portion **703**. The first ribbon portion **701** and the second ribbon portion **703** can be unmasked in several ways, for example, by rinsing the mask from the first major surface **215** and/or the second major surface **216**. In some embodiments, a liquid can be directed towards the mask **401**, **501**, **403**, **503** to remove the mask **401**, **501**, **403**, **503** from the first major surface **215** and/or the second major surface **216**. In some embodiments, a pressurized liquid can be directed at a sufficient velocity to remove the mask **401**, **501**, **403**, **503** and unmask the first ribbon portion **701** and the second ribbon portion **703**. Following the unmasking, in some embodiments, the first ribbon portion **701** and the second ribbon portion **703** can be submerged within a strengthening bath to generate compressive stress regions along one or more surfaces of the first ribbon portion **701** or the second ribbon portion **703**.

[00100] Referring to **FIG. 8**, further embodiments of methods of manufacturing the glass ribbon **104** are illustrated. In some embodiments, an initial groove **801** can be formed in the glass ribbon **104** between the first mask **401**, the second mask **403**, the third mask **405**, and the fourth mask **407**. For example, the initial groove **801** can be formed in the first unmasked area **411**, the second unmasked area **413**, the third unmasked area **415**, and the fourth unmasked area **417**. For example, referring to **FIG. 9**, a sectional view of the glass ribbon **104** is illustrated along line **9-9** of **FIG. 8**. In some embodiments, methods of manufacturing the glass ribbon **104** can comprise forming, prior to etching, the initial groove **801** at the first exposed region **509**. In some embodiments, methods of manufacturing the glass ribbon **104** can comprise forming the initial groove **801** at one or more of the first major surface **215** of the glass ribbon or the second major surface **216** of the glass ribbon **104**, wherein the initial groove **801** may be formed between the first ribbon portion **701** of the glass ribbon **104** and the second ribbon portion **703** of the glass

ribbon **104**. For example, as illustrated in **FIG. 9**, in some embodiments, the initial groove **801** can be formed in the first major surface **215** and the second major surface **216**. In some embodiments, the initial groove **801** can be formed in the first major surface **215** and not the second major surface **216**, though, in some embodiments, the initial groove **801** can be formed in the second major surface **216** and not the first major surface **215**. The initial groove **801** can be formed in several ways. For example, in some embodiments, the forming the initial groove **801** can comprise scoring the first exposed region **509** to reduce an etch time of the first exposed region **509** and the second exposed region **517**. In some embodiments, a scoring device **901** can score the first exposed region **509** to form the initial groove **801**. The scoring device **901** can comprise, for example, a laser (e.g., a CO_2 laser, a CO laser, a Bessel beam laser, a CLT laser, etc.), a scoring wheel, steel wool or sand sponge abrasion, etc. In addition or in the alternative, in some embodiments, the forming the initial groove **801** can comprise scoring the second exposed region **517** to reduce an etch time of the first exposed region **509** and the second exposed region **517**. In some embodiments, an additional scoring device **901** can score the second exposed region **517** to form the initial groove **801**.

[00101] Referring to **FIG. 10**, in some embodiments, methods of manufacturing the glass ribbon **104** can comprise etching the first exposed region **509** and the second exposed region **517** to separate the first ribbon portion **701**, comprising the first region **505** and the third region **513**, from the second ribbon portion **703**, comprising the second region **507** and the fourth region **515** along the initial groove **801** and form a first tapered edge (e.g., illustrated in **FIG. 12**) at the first ribbon portion **701** and a second tapered edge (e.g., illustrated in **FIG. 12**) at the second ribbon portion **703**. By etching the first exposed region **509** and the second exposed region **517**, the glass ribbon **104** can be exposed to the etchant **521**. For example, due to portions of the first major surface **215** and the second major surface **216** being masked (e.g., by the first mask **401**, the second mask **403**, the third mask **405**, the fourth mask **407**, the fifth mask **501**, the sixth mask **503**, etc.), the masked portions of the first major surface **215** and the second major surface **216** may be covered, sheltered, shielded, etc. In some embodiments, the masks **401**, **403**, **405**, **407**, **501**, **503**, can be resistant to etching such that areas of the first major surface **215** or the second major surface **216** that may be covered by the masks **401**, **403**, **405**, **407**, **501**, **503** may not be etched. In some embodiments, the masks **401**, **403**, **405**, **407**,

501, **503** may be impervious to the etchant, such that when the glass ribbon **104** and the masks **401**, **403**, **405**, **407**, **501**, **503** may be exposed to the etchant **521**, the masks **401**, **403**, **405**, **407**, **501**, **503** can remain on the first major surface **215** or the second major surface **216** of the glass ribbon **104**. In some embodiments, the etchant **521** can comprise one or more of from about 0% to about 50% HF, a combination of HF and HNO_3, H_sSO_4, etc.

[00102] Referring to **FIG. 11**, in some embodiments, the etchant **521** can reduce a thickness of the glass ribbon **104** at the first unmasked area **411**. For example, after exposing the first exposed region **509** and the second exposed region **517** to the etchant **521** for a period of time, a minimum thickness **1101** of the glass ribbon **104** between the first exposed region **509** and the second exposed region **517** may be reduced and may be less than the initial thickness **301** of the glass ribbon **104** at areas that may be masked (e.g., between the first region **505** and the third region **513**, between the second region **507** and the fourth region **515**, etc.). In some embodiments, the minimum thickness **1101** of the glass ribbon **104** may be located at the intermediate location **602** (e.g., midpoint) between the first mask **401** and the second mask **403**, and between the fifth mask **501** and the sixth mask **503**. In some embodiments, the etching the first exposed region **509** and the second exposed region **517** can comprise exposing the first exposed region **509** and the second exposed region **517** to the etchant **521** and concluding an exposure of the first exposed region **509** and the second exposed region **517** to the etchant **521** prior to the first ribbon portion **701** separating from the second ribbon portion **703**. For example, as illustrated in **FIG. 10**, the first exposed region **509** and the second exposed region **517** may be exposed to the etchant **521**, while in **FIG. 11**, exposure of the first exposed region **509** and the second exposed region **517** to the etchant **521** may be concluded while the first ribbon portion **701** is still attached to the second ribbon portion **703** (e.g., prior to the first ribbon portion **701** separating from the second ribbon portion **703**). For example, as illustrated in **FIG. 11**, the minimum thickness **1101** of the first unmasked area **411** may be less than the initial thickness **301** of the glass ribbon **104** at areas that may be masked, though, the first unmasked area **411** may no longer be exposed to the etchant **521**. In some embodiments, the formation of the initial groove **801** can reduce an etch time of the glass ribbon **104**.

[00103] Referring to **FIG. 12**, in some embodiments, separating the first exposed region **509** and the second exposed region **517** can comprise applying a

mechanical force to the glass ribbon **104** to separate the first ribbon portion **701** from the second ribbon portion **703** after concluding the exposure of the first exposed region **509** and the second exposed region **517** to the etchant **521**. For example, the mechanical force can be applied using an ultrasonic vibration, or other types of vibration, for example, uneven rolls, thermal shock, air bursts, etc. Due to the minimum thickness **1101** (e.g., illustrated in **FIG. 11**) of the first unmasked area **411** of the glass ribbon **104** being less than the initial thickness **301** of the glass ribbon **104** at the masked areas, the mechanical force can cause the glass ribbon **104** to break at the first unmasked area **411**, wherein a crack can propagate through the first unmasked area **411** between the first exposed region **509** and the second exposed region **517**. In some embodiments, the mechanical force can be great enough to cause the glass ribbon **104** to break at the first unmasked area **411**, but small enough to not cause the glass ribbon **104** to break at other locations, for example, the areas of the glass ribbon **104** that may be masked and comprise the initial thickness **301**. In some embodiments, the mechanical force can be applied during the etching, for example, when the mechanical force is applied by ultrasonic waves, or other methods different from applying a bending moment.

[00104] In some embodiments, the etching of the first exposed region **509** and the second exposed region **517** followed by the application of the mechanical force to the glass ribbon **104** to separate the first ribbon portion **701**, comprising the first region **505** and the third region **513**, from the second ribbon portion **703**, comprising the second region **507** and the fourth region **515**, can form a first tapered edge **1201** at the first ribbon portion **701** and a second tapered edge **1207** at the second ribbon portion **703**. For example, following the application of the mechanical force to the glass ribbon **104** and the separation of the first ribbon portion **701** from the second ribbon portion **703**, a gap **1211** can be formed in the first unmasked area **411**. When the gap **1211** is formed, the first ribbon portion **701** (e.g., comprising the first region **505** and the third region **513** of the glass ribbon **104**) can be separated from the second ribbon portion **703** (e.g., comprising the second region **507** and the fourth region **515**).

[00105] In some embodiments, the first tapered edge **1201** can comprise a thickness that may be non-constant. For example, the first tapered edge **1201** can comprise a thickness that decreases along a first axis **1221**, which may be parallel to the first major surface **215** and the second major surface **216** of the first ribbon

portion **701**, in a first direction **1223** from a center of the first ribbon portion **701** towards a perimeter of the first ribbon portion **701**. For example, the first tapered edge **1201** can comprise a first intermediate surface **1225** and a second intermediate surface **1227**. The first intermediate surface **1225** may be contiguous with the first major surface **215** of the first ribbon portion **701**, while the second intermediate surface **1227** may be contiguous with the second major surface **216** of the first ribbon portion **701**. In some embodiments, the first intermediate surface **1225** may not be co-planar with the first major surface **215** of the first ribbon portion **701**, and may be non-parallel with the first major surface **215** of the first ribbon portion **701**. In some embodiments, the second intermediate surface **1227** may not be co-planar with the second major surface **216** of the first ribbon portion **701**, and may be non-parallel with the second major surface **216** of the first ribbon portion **701**. In some embodiments, the first intermediate surface **1225** and the second intermediate surface **1227** may be non-parallel, for example, with the first intermediate surface **1225** and the second intermediate surface **1227** converging along the first axis **1221** in the first direction **1223**.

[00106] In some embodiments, the first intermediate surface **1225** and the second intermediate surface **1227** can converge at a first outer boundary **1229** of the first tapered edge **1201**. For example, the first outer boundary **1229** can comprise a first edge surface **1230** that comprises a substantially planar shape. In some embodiments, the first intermediate surface **1225** and the second intermediate surface **1227** can converge towards the first edge surface **1230**, with the first edge surface **1230** extending between the first intermediate surface **1225** and the second intermediate surface **1227**. In some embodiments, the first edge surface **1230** may extend along a first plane that may be substantially perpendicular to one or more of the first axis **1221**, the first major surface **215**, or the second major surface **216** of the first ribbon portion **701**. In some embodiments, the first edge surface **1230** can comprise a first boundary thickness **1231** between the first intermediate surface **1225** and the second intermediate surface **1227**, with the first boundary thickness **1231** being substantially equal to the minimum thickness **1101** (e.g., illustrated in **FIG. 11**) of the first unmasked area **411** when the etching is concluded. In some embodiments, the first tapered edge **1201** can comprise a truncated shape, wherein the first intermediate surface **1225** and the second intermediate surface **1227** do not converge to a point, but, rather, the first intermediate surface **1225** and the second intermediate

surface **1227** converge to the first edge surface **1230** that separates the first intermediate surface **1225** and the second intermediate surface **1227**.

[00107] In some embodiments, the second tapered edge **1207** can comprise a size, shape, and dimension that substantially matches the first tapered edge **1201**. For example, the second tapered edge **1207** can comprise a thickness that may be non-constant. In some embodiments, the second tapered edge **1207** can comprise a thickness that decreases along a second axis **1232**, which may be parallel to the first major surface **215** and the second major surface **216** of the second ribbon portion **703**, in a second direction **1233** from a center of the second ribbon portion **703** towards a perimeter of the second ribbon portion **703**. For example, the second tapered edge **1207** can comprise a third intermediate surface **1235** and a fourth intermediate surface **1237**. The third intermediate surface **1235** may be contiguous with the first major surface **215** of the second ribbon portion **703**, while the fourth intermediate surface **1237** may be contiguous with the second major surface **216** of the second ribbon portion **703**. In some embodiments, the third intermediate surface **1235** may not be co-planar with the first major surface **215** of the second ribbon portion **703**, and may be non-parallel with the first major surface **215** of the second ribbon portion **703**. In some embodiments, the fourth intermediate surface **1237** may not be co-planar with the second major surface **216** of the second ribbon portion **703**, and may be non-parallel with the second major surface **216** of the second ribbon portion **703**. In some embodiments, the third intermediate surface **1235** and the fourth intermediate surface **1237** may be non-parallel, for example, with the third intermediate surface **1235** and the fourth intermediate surface **1237** converging along the second axis **1232** in the second direction **1233**.

[00108] In some embodiments, the third intermediate surface **1235** and the fourth intermediate surface **1237** can converge at a second outer boundary **1239** of the second tapered edge **1207**. For example, the second outer boundary **1239** can comprise a second edge surface **1240** that comprises a substantially planar shape. In some embodiments, the third intermediate surface **1235** and the fourth intermediate surface **1237** can converge towards the second edge surface **1240**, with the second edge surface **1240** extending between the third intermediate surface **1235** and the fourth intermediate surface **1237**. In some embodiments, the second edge surface **1240** may extend along a second plane that may be substantially perpendicular to one or more of the second axis **1232**, the first major surface **215**, or the second major

surface **216** of the second ribbon portion **703**. In some embodiments, the second edge surface **1240** can comprise a second boundary thickness **1241** between the third intermediate surface **1235** and the fourth intermediate surface **1237**, with the second boundary thickness **1241** being substantially the same as one or more of the minimum thickness **1101** (e.g., illustrated in **FIG. 11**) of the first unmasked area **411** when the etching is concluded or the first boundary thickness **1231**. In some embodiments, the second tapered edge **1207** can comprise a truncated shape, wherein the third intermediate surface **1235** and the fourth intermediate surface **1237** do not converge to a point, but, rather, the third intermediate surface **1235** and the fourth intermediate surface **1237** converge to the second edge surface **1240** that separates the third intermediate surface **1235** and the fourth intermediate surface **1237**.

[00109] Referring to **FIG. 13**, in some embodiments, the first intermediate surface **1225** and the second intermediate surface **1227** can be cleaned and/or etched after the first ribbon portion **701** has been separated from the second ribbon portion **703**. For example, with the first mask **401**, the second mask **403**, the fifth mask **501**, and the sixth mask **503** covering the first major surface **215** and the second major surface **216** of the first ribbon portion **701** and the second ribbon portion **703**, the cleaning can comprise a final etching of the first tapered edge **1201** and the second tapered edge **1207**. For example, the first tapered edge **1201** and the second tapered edge **1207** can be exposed to a second etchant **1301**. In some embodiments, etching the first exposed region **509** (e.g., illustrated in **FIGS. 9-11**) and the second exposed region **517** (e.g., illustrated in **FIGS. 9-11**) comprises, following the separation of the first ribbon portion **701** from the second ribbon portion **703**, exposing the first tapered edge **1201** and the second tapered edge **1207** to the second etchant **1301**. In some embodiments, the second etchant **1301** can be similar to the etchant **521**, and may comprise one or more of from about 0% to about 50% HF, a combination of HF and HNO_3, H_sSO_4, etc., though, in some embodiments, the second etchant **1301** can comprise a different material than the etchant **521**. By controlling etching time and/or the material of the second etchant **1301**, defects on surfaces **1225**, **1227**, **1230** of the first ribbon portion **701** and/or on surfaces **1235**, **1237**, **1240** of the second ribbon portion **703** can be removed.

[00110] Referring to **FIG. 14**, further embodiments of methods of manufacturing the glass ribbon **104** are illustrated. **FIG. 14** illustrates a top view of the glass ribbon **104** in which a portion of the glass ribbon **104** is masked. For

example, a first mask **1401** can be positioned to cover the first major surface **215** of the glass ribbon **104**. In some embodiments, unmasked areas may exist along edges of the glass ribbon **104**, though, a central portion of the glass ribbon **104** may be covered by the first mask **1401**. In some embodiments, the glass ribbon **104** can comprise one or more ribbon portions, for example, a first ribbon portion **1403**, a second ribbon portion **1405**, a third ribbon portion **1407**, and a fourth ribbon portion **1409**. The first ribbon portion **1403**, the second ribbon portion **1405**, the third ribbon portion **1407**, and the fourth ribbon portion **1409** are illustrated with dashed lines in **FIG. 14**, as the first ribbon portion **1403**, the second ribbon portion **1405**, the third ribbon portion **1407**, and the fourth ribbon portion **1409** may initially be unseparated and covered by the first mask **1401**. The dashed lines can represent a location of the first ribbon portion **1403**, the second ribbon portion **1405**, the third ribbon portion **1407**, and the fourth ribbon portion **1409** following etching and separation (e.g., illustrated in **FIGS. 15-16**). In some embodiments, a portion of the first mask **1401** can be removed to expose the first major surface **215**. The first mask **1401** can be removed in several ways, for example, by a first laser **1411** that can laser cut the first mask **1401** and remove a portion of the first mask **1401**. In some embodiments, the first laser **1411** can comprise a CO_2 laser, a CO laser, a Bessel beam laser, etc. The first laser **1411** can move relative to the glass ribbon **104**, which may remain stationary, though, in some embodiments, the glass ribbon **104** can move relative to the first laser **1411**, with the first laser **1411** remaining stationary.

[00111] Referring to **FIG. 15**, a sectional view of the glass ribbon **104** is illustrated along line **15-15** of **FIG. 14**. In some embodiments, methods of manufacturing the glass ribbon **104** can comprise initially masking the first major surface **215** and the second major surface **216** of the glass ribbon **104**. For example, the first mask can be positioned to cover the first major surface **215** while a second mask **1501** can be positioned to cover the second major surface **216** of the glass ribbon **104**. In some embodiments, the first mask **1401** and the second mask **1501** can be positioned to cover the corresponding region in several ways, for example, by lamination, screen printing, etc. In some embodiments, the first mask **1401** and the second mask **1501** can comprise a material that may be resistant to an etchant to which the glass ribbon **104** may be exposed. For example, the first mask **1401** and/or the second mask **1501** can comprise one or more of a Vitayon HF resistant ink or

other etch resistant type inks, a photolithography resist (e.g., AZP4620, etc.), a polystyrene material with a silane modification, a laminated film, etc.

[00112] In some embodiments, methods of manufacturing the glass ribbon **104** can comprise unmasking a first exposed region **1503** of the first major surface **215** and a second exposed region **1505** of the second major surface **216**. In some embodiments, the unmasking the first exposed region **1503** and the second exposed region **1505** can comprise directing a laser beam towards the first mask **1401** covering the first exposed region **1503** and a second mask **1501** covering the second exposed region **1505**. For example, the first laser **1411** can direct a first laser beam **1507** towards the portion of the first mask **1401** that covers the first exposed region **1503** of the first major surface **215**. In some embodiments, the first laser beam **1507** can ablate and remove the portion of the first mask **1401** that covers the first exposed region **1503**. In some embodiments, a second laser **1509** can be provided for unmasking the second exposed region **1505**. The second laser **1509** can be similar to the first laser **1411**, and may comprise a CO_2 laser, a CO laser, a Bessel beam laser, etc. In some embodiments, the second laser **1509** can direct a second laser beam **1511** towards the portion of the second mask **1501** that covers the second exposed region **1505** of the second major surface **216**. In some embodiments, the second laser beam **1511** can ablate and remove the portion of the second mask **1501** that covers the second exposed region **1505**.

[00113] Referring to **FIG. 16**, following the unmasking of the first exposed region **1503** and the second exposed region **1505**, the first mask **1401** may cover a portion of the first major surface **215** while the second mask **1501** may cover a portion of the second major surface **216**. For example, the first mask **1401** can comprise a first mask portion **1601** and a second mask portion **1603**, while the second mask **1501** can comprise a third mask portion **1605** and a fourth mask portion **1607**. The first mask portion **1601** can cover a first region **1611** of the first major surface **215**, while the second mask portion **1603** can cover a second region **1613** of the first major surface **215**. The first exposed region **1503** can lie between the first region **1611** and the second region **1613**. In some embodiments, the third mask portion **1605** can cover a third region **1615** of the second major surface **216**, while the fourth mask portion **1607** can cover a fourth region **1617** of the second major surface **216**. The second exposed region **1505** can lie between the third region **1615** and the fourth region **1617**. In some embodiments, an initial groove (e.g., illustrated in **FIG. 17**)

may not be formed in the first exposed region **1503** and the second exposed region **1505**. Rather, the first exposed region **1503** and the second exposed region **1505** can be exposed to the etchant **521** (e.g., illustrated in **FIG. 5**) in a similar manner as illustrated and described relative to **FIGS. 5-7**. For example, the etchant **521** can etch the first exposed region **1503** and the second exposed region **1505** to separate the first ribbon portion **1403** from the second ribbon portion **1405**. In addition, the etching of the first exposed region **1503** and the second exposed region **1505** can form the first tapered edge **705** at the first ribbon portion **1403** and the second tapered edge **707** at the second ribbon portion **1405**.

[00114] Referring to **FIG. 17**, in some embodiments, following the unmasking of the first exposed region **1503** and the second exposed region **1505** (e.g., illustrated in **FIG. 15**), methods of manufacturing the glass ribbon **104** can comprise forming an initial groove **1701** at one or more of the first exposed region **1503** or the second exposed region **1505**, the initial groove **1701** formed between the first ribbon portion **1403** of the glass ribbon **104** and the second ribbon portion **1405** of the glass ribbon **104**. In some embodiments, the initial groove **1701** may be similar to the initial groove **801** illustrated in **FIG. 10**. For example, the initial groove **1701** can be formed in both the first exposed region **1503** and the second exposed region **1505**, with the initial groove **1701** comprising a channel, a trench, an opening, etc. The initial groove **1701** can be formed in several ways. In some embodiments, the forming the initial groove **1701** can comprise directing the first laser beam **1507** (e.g., illustrated in **FIG. 17**) towards the first exposed region **1503** to form the initial groove **1701** in the first exposed region **1503**, and directing the second laser beam **1511** (e.g., illustrated in **FIG. 17**) towards the second exposed region **1505** to form the initial groove **1701** in the second exposed region **1505**. In some embodiments, the initial groove **1701** may be formed simultaneously with the removal of the mask portions. The initial groove **1701** may not be limited to being formed by a laser, and in some embodiments, the forming the initial groove **1701** can comprise scoring the first exposed region **1503** to reduce an etch time of the first exposed region **1503** and the second exposed region **1505**. For example, the initial groove **1701** can be formed in a similar manner as illustrated and described relative to **FIG. 9**. In some embodiments, the scoring device **901** (e.g., illustrated in **FIG. 9**) can score the first exposed region **1503** and/or the second exposed region **1505** to form the initial groove **1701**. The scoring device **901** can comprise, for example, a scoring wheel, steel wool or sand

sponge abrasion, etc. Following the formation of the initial groove **1701**, the first exposed region **1503** and the second exposed region **1505** can be exposed to the etchant **521** (e.g., illustrated in **FIG. 10**) in a similar manner as illustrated and described relative to **FIGS. 10-13**. For example, the etchant **521** can etch the first exposed region **1503** and the second exposed region **1505** followed by applying a mechanical force to separate the first ribbon portion **1403** from the second ribbon portion **1405**. In addition, the etching and the application of the mechanical force can form the first tapered edge **1201** at the first ribbon portion **1403** and the second tapered edge **1207** at the second ribbon portion **1405**.

[00115] In some embodiments, the initial groove **1701** can be substantially continuous about the first ribbon portion **1403**, the second ribbon portion **1405**, the third ribbon portion **1407**, and/or the fourth ribbon portion **1409**. However, the initial groove **1701** may not be limited to extending continuously. For example, in some embodiments, the forming the initial groove **1701** can comprise directing the laser beam (e.g., the first laser beam **1507**, the second laser beam **1511**) towards the first exposed region **1503** to perforate the first exposed region **1503** at a plurality of locations to reduce an etch time of the first exposed region **1503** and the second exposed region **1505**. For example, **FIG. 18** illustrates an enlarged view of a portion of the glass ribbon **104** and the first mask **1401** taken at view 18 of **FIG. 14** after the first exposed region **1503** has been exposed and the initial groove **1701** has been formed. In some embodiments, the initial groove **1701** can comprise a plurality of perforations **1801** at a plurality of locations, wherein the perforations **1801** may be separated from adjacent perforations **1801**. In some embodiments, the perforations **1801** can extend partially or completely through the glass ribbon **104**. The perforations **1801** can be formed by the laser ablating the first major surface **215**. In some embodiments, the perforations **1801** are not limited to being formed in the first major surface **215**, and, in addition or in the alternative, the perforations **1801** can be formed in the second major surface **216**. Following the formation of the perforations **1801**, the glass ribbon **104** can be etched in a similar manner as described above to separate the first ribbon portion **1403** from the second ribbon portion **1405** and form the first tapered edge **1201** and the second tapered edge **1207**. Due to the perforations **1801** formed in the glass ribbon **104**, an etch time of the glass ribbon **104** at the initial groove **1701** may be reduced. In some embodiments, the forming the initial groove **1901** can comprise perforating the first major surface **215** at a plurality of locations

(e.g., the perforations **1801**) between a first ribbon portion **1903** and a second ribbon portion **1905**. For example, the forming the initial groove **1901** can comprise perforating the first exposed region **1503** at a plurality of locations (e.g., the perforations **1801**) to reduce the etch time of the first exposed region **1503** and the second exposed region **1505**.

[00116] Referring to **FIG. 19**, further embodiments of methods of manufacturing the glass ribbon **104** are illustrated. In some embodiments, an initial groove **1901** can be formed in the glass ribbon **104**. The glass ribbon **104** can initially be unmasked, for example, with the first major surface **215** and the second major surface **216** substantially exposed. For example, referring to **FIG. 20**, a sectional view of the glass ribbon **104** is illustrated along line **20-20** of **FIG. 19**. In some embodiments, methods of manufacturing the glass ribbon **104** can comprise forming, prior to etching, the initial groove **1901** at one or more of the first major surface **215** of the glass ribbon **104** or the second major surface **216** of the glass ribbon. The initial groove **1901** can be formed between the first ribbon portion **1903** of the glass ribbon **104** and the second ribbon portion **1905** of the glass ribbon **104**. In some embodiments, the initial groove **1901** can be formed in the first major surface **215** and not the second major surface **216**. In some embodiments, the initial groove **1901** can be formed in the second major surface **216** and not the first major surface **215**. The initial groove **1901** can be formed in several ways. For example, in some embodiments, the forming the initial groove **1901** can comprise scoring the first major surface **215** between the first ribbon portion **1903** and the second ribbon portion **1905**. In some embodiments, the scoring device **901** can score the first major surface **215** and/or the second major surface **216** to form the initial groove **1901**. In some embodiments, the forming the initial groove **1901** can comprise perforating the first major surface **215** to form the perforations **1801** (e.g., as illustrated in **FIG. 18**). In some embodiments, prior to the glass ribbon **104** being exposed to an etchant **2101**, the glass ribbon **104** can comprise an initial thickness **2103**.

[00117] Referring to **FIG. 21**, in some embodiments, the glass ribbon **104** can be exposed to the etchant **2101**. For example, due to the glass ribbon **104** being unmasked, the first major surface **215** and the second major surface **216** can be exposed to the etchant **2101**. In some embodiments, the etchant **2101** can comprise one or more of from about 0% to about 50% HF, a combination of HF and HNO_3, H_sSO_4, etc. Due to the etchant **2101** contacting the first major surface **215**, the second

major surface **216**, and the initial groove **1901**, a thickness of the glass ribbon **104** can be reduced. In some embodiments, the initial thickness **2103** of the glass ribbon **104**, prior to being exposed to the etchant **2101**, can be greater than about 200 μm. For example, the initial thickness **2103** can be within a range from about 400 μm to about 700 μm, or within a range from about 500 μm to about 600 μm. In some embodiments, the initial thickness **2103** may be larger than a final target thickness due to the subsequent exposure of the glass ribbon **104** to the etchant **2101** reducing a thickness of the glass ribbon **104**.

[00118] Referring to **FIG. 22**, in some embodiments, glass ribbon **104** can be exposed to the etchant **2101** for a period of time. For example, etching the glass ribbon **104** can comprise exposing the first major surface **215** and the second major surface **216** to the etchant **2101** and concluding the exposure of the first major surface **215** and the second major surface **216** to the etchant **2101** prior to the first ribbon portion **1903** separating from the second ribbon portion **1905**. Due to the first major surface **215** and the second major surface **216** being exposed to the etchant **2101**, the thickness of the glass ribbon **104** can be reduced. For example, after a period of time has passed during which the first major surface **215** and the second major surface **216** may be exposed to the etchant **2101**, a secondary thickness **2201** of the glass ribbon **104** can be less than the initial thickness **2103**. In some embodiments, the first major surface **215** can comprise a first groove surface **2203** that corresponds to an initial location of the initial groove **1901** in the first major surface **215**. In some embodiments, the second major surface **216** can comprise a second groove surface **2205** that corresponds to an initial location of the initial groove **1901** in the second major surface **216**. A minimum distance **2207** can be defined between the first groove surface **2203** and the second groove surface **2205**, wherein the minimum distance **2207** can define a minimum thickness of the glass ribbon **104**. By concluding the exposure of the first major surface **215** and the second major surface **216** to the etchant **2101** prior to the first ribbon portion **1903** separating from the second ribbon portion **1905**, the first ribbon portion **1903** may remain attached to the second ribbon portion **1905**. In some embodiments, the formation of the initial groove **1901** can reduce the etch time of the glass ribbon **104**.

[00119] Referring to **FIG. 23**, in some embodiments, methods of manufacturing the glass ribbon **104** can comprise applying a mechanical force to the glass ribbon **104** to separate the first ribbon portion **1903** from the second ribbon

portion **1905** after concluding the exposure of the first major surface **215** and the second major surface **216** to the etchant **2101**. For example, the mechanical force can be applied using an ultrasonic vibration, or other types of vibration, for example, uneven rolls, thermal shock, air bursts, etc. Due to the minimum distance **2207** (e.g., illustrated in **FIG. 22**) between the first groove surface **2203** and the second groove surface **2205** being less than the secondary thickness **2201** of the glass ribbon **104**, the mechanical force can cause the glass ribbon **104** to break at the first groove surface **2203** and the second groove surface **2205**, wherein a crack can propagate through the glass ribbon **104** between the first ribbon portion **1903** and the second ribbon portion **1905**. In some embodiments, the mechanical force can be great enough to cause the glass ribbon **104** to break at the first groove surface **2203** and the second groove surface **2205**, but small enough to not cause the glass ribbon **104** to break at other locations, for example, the thicker areas of the glass ribbon **104** that comprise the secondary thickness **2201**. Following the separation of the first ribbon portion **1903** from the second ribbon portion **1905**, the first ribbon portion **1903** can comprise the first tapered edge **1201** while the second ribbon portion **1905** can comprise the second tapered edge **1207**. In some embodiments, the first tapered edge **1201** and the second tapered edge **1207** can be substantially similar to the first tapered edge **1201** and the second tapered edge **1207** that are illustrated and described relative to **FIG. 12**. In some embodiments, similar to the embodiments illustrated and described relative to **FIG. 13**, the first ribbon portion **1903** and the second ribbon portion **1905** can be exposed to a second etchant **2301**. In some embodiments, the second etchant **2301** can be similar to the etchant **2101** and may comprise one or more of from about 0% to about 50% HF, a combination of HF and HNO_3, H_sSO_4, etc., though, in some embodiments, the second etchant **2301** can comprise a different material than the etchant **2101**. Exposing the first ribbon portion **1903** and the second ribbon portion **1905** to the second etchant **2301** can, in some embodiments, remove defects on the surfaces of the first ribbon portion **1903** and/or the second ribbon portion **1905**.

[00120] In some embodiments, methods of manufacturing the glass ribbon **104** can comprise etching the glass ribbon **104** to reduce a thickness of the glass ribbon **104** and separate the first ribbon portion **1903** from the second ribbon portion **1905** along the initial groove **1901** such that the first tapered edge **1201** may be formed at the first ribbon portion **1903** and the second tapered edge **1207** may be formed at the second ribbon portion **1905**. For example, due to the glass ribbon **104**

being unmasked during the etching (e.g., illustrated in **FIGS. 21-23**), the thickness of the glass ribbon **104** can be reduced as a result of the exposure of the first major surface **215** and the second major surface **216** to the etchant **2101** and/or the second etchant **2301**. In some embodiments, the first ribbon portion **1903** and the second ribbon portion **1905** can comprise a final thickness **2303** that may be less than the initial thickness **2103** (e.g., illustrated in **FIG. 21**) and the secondary thickness **2201** (e.g., illustrated in **FIG. 22**). For example, the final thickness **2303** can be within a range from about 20 μm to about 200 μm or within a range from about 25 μm to about 125 μm. Accordingly, the glass ribbon **104** can initially comprise a larger than target thickness (e.g., the initial thickness **2103**), and, following the etching, the glass ribbon **104** can comprise a target thickness (e.g., the final thickness **2303**) due to the exposure of the first major surface **215** and/or the second major surface **216** to the etchant **2101** and/or the second etchant **2301**.

[00121] Referring to **FIG. 24**, in some embodiments, methods of manufacturing the glass ribbon **104** are not limited to concluding the exposure of the first major surface **215** and the second major surface **216** to the etchant **2101** prior to the first ribbon portion **1903** separating from the second ribbon portion **1905**. Rather, similar to the embodiments illustrated and described relative to **FIGS. 5-8**, etching the glass ribbon **104** can comprise exposing the first major surface **215** and the second major surface **216** to the etchant **2101** for a period of time until the first ribbon portion **1903** may be separated from the second ribbon portion and the gap **711** may be formed between the first tapered edge **705** of the first ribbon portion **1903** and the second tapered edge **707** of the second ribbon portion **1905**. In some embodiments, methods of manufacturing the glass ribbon **104** can comprise etching the glass ribbon **104** to reduce the thickness of the glass ribbon **104** and separate the first ribbon portion **1903** from the second ribbon portion **1905** along the initial groove **1901** such that the first tapered edge **705** may be formed at the first ribbon portion **1903** and the second tapered edge **707** may be formed at the second ribbon portion **1905**. For example, due to the glass ribbon **104** being unmasked during the etching (e.g., illustrated in **FIGS. 21-23**), the thickness of the glass ribbon **104** can be reduced as a result of the exposure of the first major surface **215** and the second major surface **216** to the etchant **2101**. In some embodiments, the first ribbon portion **1903** and the second ribbon portion **1905** can comprise a final thickness **2401** that may be less than the initial thickness **2103** (e.g., illustrated in **FIG. 21**) and the secondary thickness

2201 (e.g., illustrated in **FIG. 22**). For example, the final thickness **2401** can be within a range from about 20 μm to about 200 μm or within a range from about 25 μm to about 125 μm. Accordingly, the glass ribbon **104** can initially comprise a larger than target thickness (e.g., the initial thickness **2103**), and, following the etching, the glass ribbon **104** can comprise a target thickness (e.g., the final thickness **2303**) due to the exposure of the first major surface **215** and/or the second major surface **216** to the etchant **2101**.

[00122] Referring to **FIG. 25**, some embodiments of one or more of the ribbon portions **701**, **703**, **1903**, **1905** are illustrated. In some embodiments, a ribbon portion **2501** can be formed in a similar manner to the first ribbon portion **701** and/or the second ribbon portion **703** of **FIG. 12**, or the first ribbon portion **1903** and/or the second ribbon portion **1905** of **FIG. 23**. The ribbon portion **2501** can be formed from the glass ribbon **104** illustrated in **FIG. 3**, and may be substantially similar to the first ribbon portion **701**, the second ribbon portion **703**, the first ribbon portion **1903**, and/or the second ribbon portion **1905**. In some embodiments, the ribbon portion **2501** of the glass ribbon **104** can be unmasked to expose the first major surface **215** and the second major surface **216**. The ribbon portion **2501** can be unmasked in several ways, for example, by rinsing the mask from the first major surface **215** and/or the second major surface **216**. In some embodiments, a liquid can be directed towards the first major surface **215** and the second major surface **216** to remove a mask (e.g., the first mask **401**) from the first major surface **215** and a mask (e.g., the fifth mask **501**) from the second major surface **216**. In some embodiments, a pressurized liquid can be directed at a sufficient velocity to unmask the ribbon portion **2501**.

[00123] In some embodiments, the ribbon portion **2501** can comprise the first major surface **215** extending along a first plane **2503** and the second major surface **216** extending along a second plane **2505** substantially parallel to the first plane **2503**. The ribbon portion **2501** of the glass ribbon **104** can comprise a first thickness **2507** that may be defined between the first major surface **215** and the second major surface along a thickness direction **2509** perpendicular to the first major surface **215**. In some embodiments, the first thickness **2507** can be substantially similar to the final thickness **751** (e.g., illustrated in **FIG. 7**) or the final thickness **2303** (e.g., illustrated in **FIG. 23**) of the glass ribbon **104**. For example, the first thickness **2507** can be within a range from about 20 μm to about 200 μm, or within a range from about 25 μm to about 125 μm.

[00124] The ribbon portion **2501** can comprise a tapered edge **2513**. In some embodiments, the tapered edge **2513** can be substantially similar to the first tapered edge **1201** and/or the second tapered edge **1207** illustrated in **FIGS. 13** and **23**. For example, the tapered edge **2513** can comprise a thickness that decreases along a first axis **2515**, which may be parallel to the first major surface **215** and the second major surface of the ribbon portion **2501**, in a first direction **2517** from a center of the ribbon portion **2501** towards a perimeter of the ribbon portion **2501**. While **FIG. 25** illustrates one edge (e.g., the tapered edge **2513**) of the ribbon portion **2501**, the remaining edges of the ribbon portion **2501** may be substantially similar in size and shape to the tapered edge **2513** illustrated in **FIG. 25**, wherein the remaining edges of the ribbon portion **2501** may be tapered similar to the tapered edge **2513**.

[00125] In some embodiments, the ribbon portion **2501** can comprise a first intermediate surface **2521**, a second intermediate surface **2523**, and an edge surface **2525**. The first intermediate surface **2521** can extend between a first outer edge **2527** of the first major surface **215** and a first outer edge **2529** of the edge surface **2525**. In some embodiments, the first intermediate surface **2521** can be substantially planar though, the first intermediate surface **2521** is not so limited and in some embodiments, the first intermediate surface **2521** can be non-planar (e.g., as illustrated in **FIG. 26**). The first intermediate surface **2521** may be non-parallel to the first major surface **215**, and, in some embodiments, the first intermediate surface **2521** may be non-parallel with the second intermediate surface **2523**. For example, the second intermediate surface **2523** can extend between a first outer edge **2533** of the second major surface **216** and a second outer edge **2535** of the edge surface **2525**. The second intermediate surface **2523** can be substantially planar, though, the second intermediate surface **2523** is not so limited, and in some embodiments, the second intermediate surface **2523** can be non-planar (e.g., as illustrated in **FIG. 26**). The second intermediate surface **2523** can extend non-parallel to the second major surface **216**. In some embodiments, an axis can intersect the first outer edge **2527** of the first major surface **215** and the first outer edge **2533** of the second major surface **216**, with the axis substantially perpendicular to the first major surface **215** and the second major surface **216**, and the axis substantially parallel to the thickness direction **2509**.

[00126] In some embodiments, the edge surface **2525** can extend between the first plane **2503** and the second plane **2505**. For example, by extending between the first plane **2503** and the second plane **2505**, the edge surface **2525** can

extend non-parallel to the first plane **2503** and the second plane **2505**. In some embodiments, the edge surface **2525** can extend along an edge plane **2541** that may be substantially perpendicular to the first plane **2503** and/or the second plane **2505**, wherein the edge plane **2541** can intersect the first plane **2503** and the second plane **2505**. The edge surface **2525**, extending between the first plane **2503** and the second plane **2505** along the edge plane **2541** that may be substantially perpendicular to the first plane **2503**, can define an outer boundary of the ribbon portion **2501**. For example, the first intermediate surface **2521** and the second intermediate surface **2523** can taper and converge from the first major surface **215** and the second major surface **216** towards the edge surface **2525**. In some embodiments, the first intermediate surface **2521** can define a first angle **2543** relative to the edge surface **2525**. In some embodiments, the first angle **2543** may be within a range from about 90 degrees to about 170 degrees. In some embodiments, the second intermediate surface **2523** can define a second angle **2545** relative to the edge surface **2525**. In some embodiments, the second angle **2545** may be within a range from about 90 degrees to about 170 degrees. In some embodiments, the first angle **2543** may be substantially equal to the second angle **2545**.

[00127] In some embodiments, a first separating length **2551** between the first outer edge **2527** of the first major surface **215** and the edge plane **2541** in a direction parallel to the first major surface **215** may be within a range from about 5 μm to about 85 μm. In some embodiments, a second separating length **2553** between the first outer edge **2533** of the second major surface **216** and the edge plane **2541** in a direction parallel to the second major surface **216** may be within a range from about 5 μm to about 85 μm. In some embodiments, the first separating length **2551** may be substantially equal to the second separating length **2553**. In some embodiments, the edge surface **2525** can comprise a height **2561** in the thickness direction **2509** that may be less than the first thickness **2507**. For example, in some embodiments, the height **2561** may be within a range from about 25 μm to about 75 μm. In some embodiments, the edge surface **2525** can be spaced a first separating thickness **2563** from the first plane **2503** from the first plane **2503** and a second separating thickness **2565** from the second plane **2505**. For example, the first separating thickness **2563** between the first outer edge **2529** of the edge surface **2525** and the first plane **2503** along a direction parallel to the edge plane **2541** may be within a range from about 25 μm to about 100 μm. In some embodiments, the second separating thickness **2565**

between the second outer edge **2535** of the edge surface **2525** and the second plane **2505** along the direction parallel to the edge plane **2541** may be within a range from about 25 μm to about 100 μm. In some embodiments, the first separating thickness **2563** may be substantially equal to the second separating thickness **2565**. However, the first separating thickness **2563** is not limited to being equal to the second separating thickness **2565**, and in some embodiments, the first separating thickness **2563** may be greater than the second separating thickness **2565**, or the first separating thickness **2563** may be less than the second separating thickness **2565**.

[00128] Referring to **FIG. 26**, further embodiments of one or more of the ribbon portions **701**, **703**, **1903**, **1905** are illustrated. In some embodiments, a ribbon portion **2601** can be formed in a similar manner as the first ribbon portion **701** and/or the second ribbon portion **703** of **FIG. 7**, or the first ribbon portion **1903** and/or the second ribbon portion **1905** of **FIG. 24**. The ribbon portion **2601** can be formed from the glass ribbon **104** illustrated in **FIG. 3**, and may be substantially similar to the first ribbon portion **701**, the second ribbon portion **703**, the first ribbon portion **1903**, and/or the second ribbon portion **1905**. In some embodiments, the ribbon portion **2601** of the glass ribbon **104** can be unmasked to expose the first major surface **215** and the second major surface **216**. The ribbon portion **2601** can be unmasked in several ways, for example, by rinsing the mask from the first major surface **215** and/or the second major surface **216**. In some embodiments, a liquid can be directed towards the first major surface **215** and the second major surface **216** to remove a mask (e.g., the first mask **401**) from the first major surface **215** and a mask (e.g., the fifth mask **501**) from the second major surface **216**. In some embodiments, a pressurized liquid can be directed at a sufficient velocity to unmask the ribbon portion **2601**. In some embodiments, the ribbon portion **2601** can comprise the first major surface **215** extending along the first plane **2503** and the second major surface **216** extending along the second plane **2505** substantially parallel to the first plane **2503**. The first thickness **2507** may be defined between the first major surface **215** and the second major surface **216**.

[00129] In some embodiments, the ribbon portion **2601** can comprise a tapered edge **2603**. The tapered edge **2603** can be substantially similar to the first tapered edge **705** and/or the second tapered edge **707** illustrated in **FIGS. 7** and **24**. For example, the tapered edge **2603** can comprise a thickness that decreases along the first axis **2515** in the first direction **2517** from the center of the ribbon portion **2601**

towards a perimeter of the ribbon portion **2601**. While **FIG. 26** illustrates one edge (e.g., the tapered edge **2603**) of the ribbon portion **2601**, the remaining edges of the ribbon portion **2601** may be substantially similar in size and shape to the tapered edge **2603** illustrated in **FIG. 26**, wherein the remaining edges of the ribbon portion **2601** may be tapered similar to the tapered edge **2603**.

[00130] In some embodiments, the ribbon portion **2601** can comprise the first intermediate surface **2521**, the second intermediate surface **2523**, and an edge surface **2605**. The first intermediate surface **2521** can extend between the first outer edge **2527** of the first major surface **215** and a first outer edge **2607** of the edge surface **2605**. The second intermediate surface **2523** can extend between the first outer edge **2533** of the second major surface **216** and a second outer edge **2609** of the edge surface **2605**. In some embodiments, the edge surface **2605** can extend between the first plane **2503** and the second plane **2505**. The edge surface **2605** can be non-planar, for example, by comprising a rounded, circular shape. The edge surface **2605** can comprise the first outer boundary **729** that can define an outermost location from a center of the ribbon portion **2601**. In some embodiments, the edge surface **2605** can comprise a radius of curvature that may be less than about half of the first thickness **2507**. For example, the radius of curvature may be within a range of from about 5 μm to about 100 μm. The ribbon portion **2601** can comprise a first separating length **2615** between the first outer edge **2527** of the first major surface **215** and the first outer boundary **729** of the edge surface **2605** in a direction parallel to the first major surface **215** that may be within a range from about 5 μm to about 85 μm. The ribbon portion **2601** can comprise a second separating length **2617** between the first outer edge **2533** of the second major surface **216** and the first outer boundary **729** of the edge surface **2605** in a direction parallel to the second major surface **216** that may be within a range from about 5 μm to about 85 μm. In some embodiments, the first separating length **2615** may be substantially equal to the second separating length **2617**. In some embodiments, the edge surface **2605** can comprise a height **2619** in the thickness direction **2509** that may be less than the first thickness **2507**. For example, the height **2619** of the edge surface **2605** can be between the first outer edge **2607** of the edge surface **2605** and the second outer edge **2609** of the edge surface **2605**. In some embodiments, the height **2619** may be within a range from about 25 μm to about 75 μm. The edge surface **2605** can be spaced a first separating thickness **2623** from the first plane **2503** and a second separating thickness **2625** from the second

plane **2505**. For example, the first separating thickness **2623** between the first outer edge **2607** of the edge surface **2605** and the first plane **2503** along the thickness direction **2509** may be within a range of from about 25 μm to about 100 μm. In some embodiments, the second separating thickness **2625** between the second outer edge **2609** of the edge surface **2605** and the second plane **2505** along the thickness direction **2509** may be within a range of from about 25 μm to about 100 μm. In some embodiments, the first separating thickness **2623** may be substantially equal to the second separating thickness **2625**. However, the first separating thickness **2623** is not limited to being equal to the second separating thickness **2625**, and in some embodiments, the first separating thickness **2623** may be greater than the second separating thickness **2625**, or the first separating thickness **2623** may be less than the second separating thickness **2625**.

[00131] In some embodiments, following the formation of the ribbon portions **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601** comprising the tapered edges **705**, **707**, **1201**, **1207**, **2513**, **2603**, the ribbon portions **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601** can be exposed to a strengthening bath. The strengthening bath can generate compressive stress regions along one or more surfaces of the ribbon portions **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601**. The ribbon portions **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601** can be exposed to the strengthening bath in several ways. In some embodiments, the ribbon portions **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601** can be immersed in a tank comprising the strengthening bath. In some embodiments, the ribbon portions **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601** can be sprayed with a strengthening bath solution to generate the compressive stress regions. Following the generation of the compressive stress regions, a protective covering can be applied to one or more surfaces of the ribbon portions **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601**.

[00132] **FIG. 27** illustrates the ribbon portion **2501** subject to a bending test to determine a stress at different locations of the ribbon portion **2501**. For example, a first plate **2701** can contact a first planar segment **2702** of the ribbon portion **2501** and apply a first force **2703** to the ribbon portion **2501** in a first direction. A second plate **2705** can contact a second planar segment **2704** of the ribbon portion **2501** and apply a second force **2707** to the ribbon portion **2501** in a second direction that is opposite the first direction. In some embodiments, the first plate **2701** and the second plate **2705** can be oriented substantially parallel to each

other, and may be spaced a distance **2709** apart. The ribbon portion **2501** can comprise a bent segment **2711** extending between the first planar segment **2702** and the second planar segment **2704**. In some embodiments, the bent segment 2711 can be non-planar and may comprise a curved shape. By increasing the first force **2703** and/or the second force **2707**, the distance **2709** between the first plate **2701** and the second plate **2705** can be increased or decreased. In some embodiments, the distance **2709** can be decreased to determine a maximum degree of bending that the ribbon portion **2501** can undergo prior to failing. Referring to **FIG. 28**, a sectional view of the ribbon portion **2501** along line **28-28** of **FIG. 27** is illustrated. In some embodiments, the ribbon portion **2501** can experience a maximum stress at the bent segment **2711**. For example, the maximum stress can be located at an outer surface of the bent segment **2711**. In some embodiments, the maximum stress can vary based on a location along a width direction **2801** of the bent segment **2711**. For example, the maximum stress at a central location **2803** of the bent segment **2711** can be different than the maximum stress at an edge location **2805** of the bent segment **2711**. The central location **2803** can be located at a midpoint of the ribbon portion **2501** between opposing edges along the width direction **2801**, while the edge location **2805** can be located at an edge of the ribbon portion **2501** along the width direction **2801**.

[00133] **FIG. 29** illustrates a relationship between a location along the width of the bent segment **2711** in the width direction **2801** and a maximum stress at that location. The x-axis (e.g., horizontal axis) represents the distance (e.g., μm) from the central location **2803** along the width direction **2801** while the y-axis (e.g., vertical axis) represents the maximum stress (e.g., megapascals, "MPa"). A line **2901** represents a maximum stress of the bent segment **2711** at a location between the central location **2803** and the edge location **2805**. In some embodiments, the line **2901** is representative of the ribbon portion **2501** comprising an edge that is non-tapered (e.g., wherein a thickness of the ribbon portion **2501** is constant from a center to an edge), and the first thickness **2507** may be about 100 μm. The 0 μm distance on the x-axis is representative of the maximum stress at the central location **2803**, while the 50 μm distance on the x-axis is representative of the maximum stress at the edge location **2805**. The other locations on the x-axis between the 0 μm distance and the 50 μm distance (e.g., 10 μm, 20 μm, 30 μm, 40 μm, etc.) are representative of the maximum stress of the bent segment **2711** at locations between the central location **2803** and the edge location **2805** along the width direction **2801**. For example, the 10

μm location may represent a location that may be 10 μm from the central location **2803** and 40 μm from the edge location **2805** along the width direction **2801**. The 20 μm location may represent a location that may be 20 μm from the central location **2803** and 30 μm from the edge location **2805** along the width direction **2801**. The 30 μm location may represent a location that may be 30 μm from the central location **2803** and 20 μm from the edge location **2805** along the width direction **2801**. The 40 μm location may represent a location that may be 40 μm from the central location **2803** and 10 μm from the edge location **2805** along the width direction **2801**. In some embodiments, as represented by the line **2901**, the maximum stress of the bent segment **2711** can be substantially constant from the 0 μm location (e.g., at the central location **2803**) to the 40 μm location, with the maximum stress within a range from about 506 MPa to about 507 MPa. The maximum stress may decrease at about the 45 μm location, in which the maximum stress reaches a minimum of about 505 MPa. After reaching this minimum, the maximum stress increases from the 45 μm location to the 50 μm location (e.g., at the edge location **2805**), with the maximum stress exceeding 517 MPa. This increase in maximum stress from the central location **2803** to the edge location **2805** may be caused, in part, by the ribbon portion **2501** comprising a non-tapered edge when the first thickness **2507** of the ribbon portion **2501** may be about 100 μm.

[00134] **FIG. 30** illustrates a relationship between a location along the width of the bent segment **2711** in the width direction **2801** and a maximum stress at that location. The x-axis (e.g., horizontal axis) represents the distance (e.g., μm) from the central location **2803** along the width direction **2801** while the y-axis (e.g., vertical axis) represents the maximum stress (e.g., mega-pascals, "MPa"). A line **3001** represents a maximum stress of the bent segment **2711** at a location between the central location **2803** and the edge location **2805**. In some embodiments, the line **3001** is representative of the ribbon portion **2501** comprising an edge that is non-tapered (e.g., wherein a thickness of the ribbon portion **2501** is constant from a center to an edge), and the first thickness **2507** is about 75 μm. The 0 μm distance on the x-axis is representative of the maximum stress at the central location **2803**, while the 50 μm distance on the x-axis is representative of the maximum stress at the edge location **2805**. The other locations on the x-axis between the 0 μm distance and the 50 μm distance (e.g., 10 μm, 20 μm, 30 μm, 40 μm, etc.) are representative of the maximum stress of the bent segment **2711** at locations between the central location **2803** and the

edge location **2805** along the width direction **2801**. For example, the 10 μm location may represent a location that may be 10 μm from the central location **2803** and 40 μm from the edge location **2805** along the width direction **2801**. The 20 μm location may represent a location that may be 20 μm from the central location **2803** and 30 μm from the edge location **2805** along the width direction **2801**. The 30 μm location may represent a location that may be 30 μm from the central location **2803** and 20 μm from the edge location **2805** along the width direction **2801**. The 40 μm location may represent a location that is 40 μm from the central location **2803** and 10 μm from the edge location **2805** along the width direction **2801**. In some embodiments, as represented by the line **3001**, the maximum stress of the bent segment **2711** can be substantially constant from the 0 μm location (e.g., at the central location **2803**) to the 40 μm location, with the maximum stress within a range from about 456 MPa to about 457 MPa. The maximum stress may decrease at about the 45 μm location, in which the maximum stress reaches a minimum of about 455.5 MPa. After reaching this minimum, the maximum stress increases from the 45 μm location to the 50 μm location (e.g., at the edge location **2805**), with the maximum stress exceeding 462 MPa. This increase in maximum stress from the central location **2803** to the edge location **2805** may be caused, in part, by the ribbon portion **2501** comprising a non-tapered edge when the first thickness **2507** of the ribbon portion **2501** may be about 75 μm.

[00135] **FIG. 31** illustrates a relationship between a location along the width of the bent segment **2711** in the width direction **2801** and a maximum stress at that location. The x-axis (e.g., horizontal axis) represents the distance (e.g., μm) from the central location **2803** along the width direction **2801** while the y-axis (e.g., vertical axis) represents the maximum stress (e.g., mega-pascals, "MPa"). A line **3101** represents a maximum stress of the bent segment **2711** at a location between the central location **2803** and the edge location **2805**. In some embodiments, the line **3101** may be representative of the ribbon portion **2501** comprising an edge that may be non-tapered (e.g., wherein a thickness of the ribbon portion **2501** may be constant from a center to an edge), and the first thickness **2507** may be about 50 μm. The 0 μm distance on the x-axis may be representative of the maximum stress at the central location **2803**, while the 50 μm distance on the x-axis may be representative of the maximum stress at the edge location **2805**. The other locations on the x-axis between the 0 μm distance and the 50 μm distance (e.g., 10 μm, 20 μm, 30 μm, 40 μm, etc.)

are representative of the maximum stress of the bent segment **2711** at locations between the central location **2803** and the edge location **2805** along the width direction **2801**. For example, the 10 μm location may represent a location that may be 10 μm from the central location **2803** and 40 μm from the edge location **2805** along the width direction **2801**. The 20 μm location may represent a location that may be 20 μm from the central location **2803** and 30 μm from the edge location **2805** along the width direction **2801**. The 30 μm location may represent a location that may be 30 μm from the central location **2803** and 20 μm from the edge location **2805** along the width direction **2801**. The 40 μm location may represent a location that may be 40 μm from the central location **2803** and 10 μm from the edge location **2805** along the width direction **2801**. In some embodiments, as represented by the line **3101**, the maximum stress of the bent segment **2711** can be substantially constant from the 0 μm location (e.g., at the central location **2803**) to the 40 μm location, with the maximum stress within a range from about 417.5 MPa to about 418 MPa. The maximum stress may decrease at about the 45 μm location, in which the maximum stress reaches a minimum that may be within a range from about 417 MPa to about 417.5 MPa. After reaching this minimum, the maximum stress increases from the 45 μm location to the 50 μm location (e.g., at the edge location **2805**), with the maximum stress exceeding 421 MPa. This increase in maximum stress from the central location **2803** to the edge location **2805** may be caused, in part, by the ribbon portion **2501** comprising a non-tapered edge when the first thickness **2507** of the ribbon portion **2501** may be about 75 μm.

[00136] **FIG. 32** illustrates a relationship between a location along the width of the bent segment **2711** in the width direction **2801** and a maximum stress at that location. The x-axis (e.g., horizontal axis) represents the distance (e.g., μm) from the central location **2803** along the width direction **2801** while the y-axis (e.g., vertical axis) represents the maximum stress (e.g., mega-pascals, "MPa"). A line **3201** represents a maximum stress of the bent segment **2711** at a location between the central location **2803** and the edge location **2805**. In some embodiments, the line **3201** may be representative of the ribbon portion **2501** comprising the tapered edge **2513**, and the first thickness **2507** may be about 100 μm. The 0 μm distance on the x-axis may be representative of the maximum stress at the central location **2803**, while the 50 μm distance on the x-axis may be representative of the maximum stress at the edge location **2805**. The other locations on the x-axis between the 0 μm distance and

the 50 μm distance (e.g., 10 μm, 20 μm, 30 μm, 40 μm, etc.) are representative of the maximum stress of the bent segment **2711** at locations between the central location **2803** and the edge location **2805** along the width direction **2801**. For example, the 10 μm location may represent a location that may be 10 μm from the central location **2803** and 40 μm from the edge location **2805** along the width direction **2801**. The 20 μm location may represent a location that may be 20 μm from the central location **2803** and 30 μm from the edge location **2805** along the width direction **2801**. The 30 μm location may represent a location that may be 30 μm from the central location **2803** and 20 μm from the edge location **2805** along the width direction **2801**. The 40 μm location may represent a location that may be 40 μm from the central location **2803** and 10 μm from the edge location **2805** along the width direction **2801**. In some embodiments, as represented by the line **3201**, the maximum stress of the bent segment **2711** can be substantially constant from the 0 μm location (e.g., at the central location **2803**) to the 45 μm location, with the maximum stress within a range from about 500 MPa to about 505 MPa. The maximum stress may then increase at about the 48 μm location, in which the maximum stress reaches a maximum that may be within a range from about 505 MPa to about 510 MPa. After reaching this maximum, the maximum stress can decrease from the 48 μm location to the 50 μm location (e.g., at the edge location **2805**), with the maximum stress falling below about 500 MPa and approaching 440 MPa.

[00137] The decrease in maximum stress from the central location **2803** to the edge location **2805** may be due, in part, to the ribbon portion **2501** comprising the tapered edge **2513** when the first thickness **2507** of the ribbon portion **2501** may be about 100 μm. In contrast to the ribbon portions that comprise a non-tapered edge (e.g., **FIGS. 29-31**) in which the maximum stress increases near the edge location **2805**, the maximum stress for the ribbon portion **2501** comprising the tapered edge **2513** can decrease near the edge location **2805**. For example, by comparing **FIG. 29**, in which the ribbon portion **2501** comprises a thickness of about 100 μm and does not comprise a tapered edge, to **FIG. 32**, which the ribbon portion **2501** comprises a thickness of about 100 μm and comprises the tapered edge **2513**, the maximum stress at the tapered edge **2513** may be different. For example, the maximum stress at the non-tapered edge (e.g., the 50 μm location in **FIG. 29**) with 100 μm thickness may be about 516 MPa while the maximum stress at the tapered edge **2513** (e.g., the 50 μm location in **FIG. 32**) with 100 μm thickness may be about 440 MPa. This difference

of about 76 MPa at the edge can allow for a reduced likelihood of damage to the ribbon portion **2501** during bending and also provide for a greater degree of bending for the ribbon portion **2501** when the ribbon portion **2501** comprises the tapered edge **2513**. The maximum stress of the bent segment **2711** in **FIG. 32** from 0 μm to 40 μm may differ slightly from the maximum stress of the bent segment **2711** in **FIG. 29** from 0 μm to 40 μm, despite the thicknesses being about the same (e.g., about 100 μm). This may be due, in part, to the line **3201** representing the ribbon portion **2501** comprising the tapered edge **2513**. In some embodiments, the tapered edge **2513** can lead to a reduction in surface area at both the first major surface **215** and the second major surface **216**. This reduction in surface area can cause a slight decrease in maximum stress (e.g., from about 507 MPa in **FIG. 29** to about 504 MPa in **FIG. 32**) at the center of the ribbon portion (e.g., from 0 μm to 40 μm).

[00138] **FIG. 33** is an enlarged view of the tapered edge **2513** of the ribbon portion **2501** at the bent segment **2711** at view **33** of **FIG. 28**. For example, the second major surface **216** in **FIG. 33** represents a bottom surface (e.g., or inner surface relative to a radius of curvature) of the bent segment **2711** of **FIG. 28**. The first major surface **215** in **FIG. 33** represents a top surface (e.g., or outer surface relative to a radius of curvature) of the bent segment **2711** of **FIG. 28**. In some embodiments, the first thickness **2507** of the ribbon portion **2501** of **FIG. 33** may be about 100 μm, while the height **2561** of the edge surface **2525** may be about 50 μm, and the distance **2709** (e.g., illustrated in **FIG. 27**) separating the first plate **2701** and the second plate **2705** may be about 30 μm. The ribbon portion **2501** illustrated in **FIG. 33** is representative of a ribbon portion that has not been subject to chemical strengthening (e.g., via an ion exchange process).

[00139] In some embodiments, the ribbon portion **2501** can comprise a first stress region **3301** that extends along the first major surface **215**. In some embodiments, the first stress region **3301** can comprise a stress (e.g., tensile stress) within a range from about 510 MPa to about 520 MPa. In some embodiments, the ribbon portion **2501** can comprise a second stress region **3303** that extends adjacent to the first stress region **3301**. The second stress region **3303** can be spaced a distance apart from the first major surface **215**, and the second stress region **3303** can comprise a portion of the first intermediate surface **2521**. In some embodiments, the second stress region **3303** can comprise a stress (e.g., tensile stress) within a range from about 480 MPa to about 510 MPa. In some embodiments, the ribbon portion **2501** can

comprise a third stress region **3305** that extends adjacent to the second stress region **3303**, wherein the second stress region **3303** may be located between the first stress region **3301** and the third stress region **3305**. The third stress region **3305** can be spaced a greater distance from the first major surface **215** than the second stress region **3303**, and the third stress region **3305** can comprise a portion of the first intermediate surface **2521**. In some embodiments, the third stress region **3305** can comprise a stress (e.g., tensile stress) within a range from about 440 MPa to about 480 MPa. In some embodiments, the ribbon portion **2501** can comprise a fourth stress region **3307** that extends adjacent to the third stress region **3305**, wherein the third stress region **3305** may be located between the second stress region **3303** and the fourth stress region **3307**. The fourth stress region **3307** can be spaced a greater distance from the first major surface **215** than the third stress region **3305**, and the fourth stress region **3307** can comprise a portion of the first intermediate surface **2521** and a portion of the edge surface **2525**. In some embodiments, the fourth stress region **3307** can comprise a stress (e.g., tensile stress) within a range from about 400 MPa to about 440 MPa. In some embodiments, the ribbon portion **2501** can comprise a fifth stress region **3309** that extends adjacent to the fourth stress region **3307**, wherein the fourth stress region **3307** may be located between the third stress region **3305** and the fifth stress region **3309**. The fifth stress region **3309** can be spaced a greater distance from the first major surface **215** than the fourth stress region **3307**, and the fifth stress region **3309** can comprise a portion of the edge surface **2525**, the second intermediate surface **2523**, and the second major surface **216**. In some embodiments, the fifth stress region **3309** can comprise a stress that may be less than about 400 MPa. For example, the fifth stress region **3309** can comprise a non-uniform stress in which a compressive stress of the fifth stress region **3309** may increase from the fourth stress region **3307** (e.g., or a center of the ribbon portion **2501**) towards the second major surface **216**. Due to the tapered edge **2513** of the ribbon portion **2501**, the stress at the bent segment **2711** can decrease from a center of the ribbon portion **2501** towards the edge surface **2525**. In some embodiments, the first major surface **215** may comprise a higher tensile stress (e.g., and lower compressive stress) than the second major surface **216**, which may have a lower tensile stress (e.g., but higher compressive stress).

[00140] **FIG. 34** illustrates a relationship between a location along the width of the bent segment **2711** (e.g., illustrated in **FIG. 28**) in the width direction

2801 and a maximum stress at that location. The x-axis (e.g., horizontal axis) represents the distance (e.g., μm) from the central location **2803** along the width direction **2801** while the y-axis (e.g., vertical axis) represents the maximum stress (e.g., mega-pascals, "MPa"). A line **3401** represents a maximum stress of the bent segment **2711** at a location between the central location **2803** and the edge location **2805**. The line **3401** is representative of the ribbon portion **2601** comprising the tapered edge **2603** (e.g., illustrated in **FIG. 26**) comprising a radius of curvature of about 50 μm. For example, the ribbon portion **2601** may be positioned between the first plate **2701** and the second plate **2705** and bent (e.g., similar to the shape in **FIG. 27**), wherein the distance **2709** between the first plate **2701** and the second plate **2705** may be about 30 μm. In some embodiments, the tapered edge **2603** comprises a rounded, half-circle shape between the first outer edge **2527** of the first major surface **215** and the first outer edge **2533** of the second major surface **216**. The first thickness **2507** of the ribbon portion **2601** may be about 100 μm. The 0 μm distance on the x-axis may be representative of the maximum stress at the central location **2803**, while the 50 μm distance on the x-axis may be representative of the maximum stress at the edge location **2805**. The other locations on the x-axis between the 0 μm distance and the 50 μm distance (e.g., 10 μm, 20 μm, 30 μm, 40 μm, etc.) are representative of the maximum stress of the bent segment **2711** at locations between the central location **2803** and the edge location **2805** along the width direction **2801**. For example, the 10 μm location may represent a location that may be 10 μm from the central location **2803** and 40 μm from the edge location **2805** along the width direction **2801**. The 20 μm location may represent a location that may be 20 μm from the central location **2803** and 30 μm from the edge location **2805** along the width direction **2801**. The 30 μm location may represent a location that may be 30 μm from the central location **2803** and 20 μm from the edge location **2805** along the width direction **2801**. The 40 μm location may represent a location that may be 40 μm from the central location **2803** and 10 μm from the edge location **2805** along the width direction **2801**. In some embodiments, as represented by the line **3401**, the maximum stress of the bent segment **2711** can be substantially constant from the 0 μm location (e.g., at the central location **2803**) to the 45 μm location, with the maximum stress within a range from about 500 MPa to about 510 MPa. The maximum stress may then increase at about the 49 μm location, in which the maximum stress reaches a maximum that may be within a range from about 510 MPa to about 515 MPa. After reaching this maximum,

the maximum stress can decrease from the 49 μm location to the 50 μm location (e.g., at the edge location **2805**), with the maximum stress falling below about 500 MPa and approaching 400 MPa.

[00141] **FIG. 35** is an enlarged view of the tapered edge **2603** of the ribbon portion **2601** at the bent segment **2711** at view **33** of **FIG. 28** comprising maximum stresses represented by the line **3401** in **FIG. 34**. For example, the second major surface **216** in **FIG. 35** represents a bottom surface (e.g., or inner surface relative to a radius of curvature) of the bent segment **2711** of **FIG. 28**. The first major surface **215** in **FIG. 33** represents a top surface (e.g., or outer surface relative to a radius of curvature) of the bent segment **2711** of **FIG. 28**. In some embodiments, the first thickness **2507** of the ribbon portion **2601** may be about 100 μm, while the tapered edge **2603** may comprise a radius of curvature of about 50 μm. The ribbon portion **2601** illustrated in **FIG. 33** is representative of a ribbon portion that has not been subject to chemical strengthening (e.g., via an ion exchange process).

[00142] In some embodiments, the ribbon portion **2601** can comprise a first stress region **3501** that extends along the first major surface **215**. In some embodiments, the first stress region **3501** can comprise a stress (e.g., tensile stress) within a range from about 469 MPa to about 512 MPa. In some embodiments, the ribbon portion **2601** can comprise a second stress region **3503** that extends adjacent to the first stress region **3501**. The second stress region **3503** can comprise a stress (e.g., tensile stress) within a range from about 427 MPa to about 469 MPa. In some embodiments, the ribbon portion **2601** can comprise a third stress region **3505** that extends adjacent to the second stress region **3503**, wherein the second stress region **3503** may be located between the first stress region **3501** and the third stress region **3505**. The third stress region **3505** can be spaced a greater distance from the first major surface **215** than the second stress region **3503**. In some embodiments, the third stress region **3505** can comprise a stress (e.g., tensile stress) within a range from about 394 MPa to about 427 MPa. In some embodiments, the ribbon portion **2601** can comprise a fourth stress region **3507** that extends adjacent to the third stress region **3505**, wherein the third stress region **3505** may be located between the second stress region **3503** and the fourth stress region **3507**. The fourth stress region **3507** may be spaced a greater distance from the first major surface **215** than the third stress region **3505**. In some embodiments, the fourth stress region **3507** can comprise a stress (e.g., tensile stress) within a range from about 0 MPa to about 394 MPa. In

some embodiments, the ribbon portion **2601** can comprise a fifth stress region **3509** that extends adjacent to the fourth stress region **3507** and along the second major surface **216**. In some embodiments, the fifth stress region **3509** can comprise a stress that may be less than about 0 MPa. The fifth stress region **3509** can comprise a non-uniform stress in which a compressive stress of the fifth stress region **3509** may increase from the fourth stress region **3507** (e.g., or a center of the ribbon portion **2601**) towards the second major surface **216**. Due to the tapered edge **2603** of the ribbon portion **2601** comprising a rounded, half-circle shape, the stress at the bent segment **2711** can decrease from a center of the ribbon portion **2601** towards the tapered edge **2603**. In some embodiments, the first major surface **215** may comprise a higher tensile stress (e.g., and lower compressive stress) than the second major surface **216**, which may have a lower tensile stress (e.g., but higher compressive stress).

[00143] As disclosed herein, the ribbon portions **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601** can be thin, for example, by comprising a thickness within a range from about 20 micrometers (μm) to about 200 μm or within a range from about 25 μm to about 125 μm. The ribbon portions **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601** can be formed in a continuous manner, in which a glass ribbon **104** can be separated into discrete ribbon portions (e.g., the ribbon portions **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601**, etc.) with tapered edge shapes (e.g., tapered edges **705**, **707**, **1201**, **1207**, **2513**, **2603**). In some embodiments, the glass ribbon **104** can comprise an initial thickness that may either be a target thickness, or may be larger than a target thickness. In either scenario, the glass ribbon **104** can be separated into discrete ribbon portions with tapered edge shapes and a target thickness. The likelihood of damage to the ribbon portions (e.g., the ribbon portions **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601**, etc.) may also be reduced due to a lack of grinding or polishing of the edges, and also due to a lack of stacking of the ribbon portions. By producing the tapered edges through chemical formation, sharp corners at the edges may also be avoided. The tapered edges **705**, **707**, **1201**, **1207**, **2513**, **2603** of the ribbon portions **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601** can also reduce the likelihood of damage to the ribbon portions **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601** during bending. For example, during bending, the maximum stress at a bent segment of the ribbon portion **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601** may comprise a reduced stress near the tapered edge **705**, **707**, **1201**, **1207**, **2513**, **2603** as compared to a ribbon

portion with a non-tapered edge. Due to this lower stress near the tapered edge **705**, **707**, **1201**, **1207**, **2513**, **2603**, improved bending of the ribbon portion **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601** can be achieved. In addition, the lower stress near the tapered edge **705**, **707**, **1201**, **1207**, **2513**, **2603** of the ribbon portion **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601** may improve the strength of the ribbon portion **701**, **703**, **1403**, **1405**, **1903**, **1905**, **2501**, **2601**, thus reducing the likelihood of inadvertent breakage, for example, during bending.

[00144] As used herein the terms "the," "a," or "an," mean "one or more," and should not be limited to "only one" unless explicitly indicated to the contrary. Thus, for example, reference to "a component" includes embodiments having two or more such components unless the context clearly indicates otherwise.

[00145] As used herein, the term “about” means that amounts, sizes, formulations, parameters, and other quantities and characteristics are not and need not be exact, but may be approximate and/or larger or smaller, as desired, reflecting tolerances, conversion factors, rounding off, measurement error and the like, and other factors known to those of skill in the art. When the term “about” is used in describing a value or an end-point of a range, the disclosure should be understood to include the specific value or end-point referred to. Whether or not a numerical value or end-point of a range in the specification recites “about,” the numerical value or end-point of a range is intended to include two embodiments: one modified by “about,” and one not modified by “about.” 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.

[00146] The terms “substantial,” “substantially,” and variations thereof as used herein are intended to note that a described feature is equal or approximately equal to a value or description. For example, a “substantially planar” surface is intended to denote a surface that is planar or approximately planar. Moreover, as defined above, “substantially similar” is intended to denote that two values are equal or approximately equal. In some embodiments, “substantially similar” may denote values within about 10% of each other, for example within about 5% of each other, or within about 2% of each other.

[00147] As used herein, the terms “comprising” and “including,” and variations thereof shall be construed as synonymous and open-ended, unless otherwise indicated.

[00148] It should be understood that while various embodiments have been described in detail relative to certain illustrative and specific embodiments thereof, the present disclosure should not be considered limited to such, as numerous modifications and combinations of the disclosed features are envisioned without departing from the scope of the following claims.

What is claimed is:

1. A method of manufacturing a glass ribbon comprising:

masking a first region and a second region of a first major surface of the glass ribbon, such that the first major surface comprises a first exposed region between the first region and the second region;

masking a third region and a fourth region of a second major surface of the glass ribbon, such that the second major surface comprises a second exposed region between the third region and the fourth region; and

etching the first exposed region and the second exposed region to separate a first ribbon portion, comprising the first region and the third region, from a second ribbon portion, comprising the second region and the fourth region, and form a first tapered edge at the first ribbon portion and a second tapered edge at the second ribbon portion.

2. The method of claim 1, further comprising forming, prior to etching, an initial groove at the first exposed region.

3. The method of claim 2, wherein the forming the initial groove comprises perforating the first exposed region at a plurality of locations.

4. The method of claim 2, wherein the forming the initial groove comprises scoring the first exposed region.

5. The method of any one of claims 1-4, wherein the etching the first exposed region and the second exposed region comprises exposing the first exposed region and the second exposed region to an etchant for a period of time until the first ribbon portion is separated from the second ribbon portion and a gap is formed between the first tapered edge of the first ribbon portion and the second tapered edge of the second ribbon portion.

6. The method of any one of claims 1-4, wherein the etching the first exposed region and the second exposed region comprises exposing the first exposed region and the second exposed region to an etchant and concluding an exposure of the first

exposed region and the second exposed region to the etchant prior to the first ribbon portion separating from the second ribbon portion.

7. The method of claim 6, further comprising applying a mechanical force to the glass ribbon to separate the first ribbon portion from the second ribbon portion after concluding the exposure of the first exposed region and the second exposed region to the etchant.

8. The method of claim 7, wherein the etching the first exposed region and the second exposed region comprises, following a separation of the first ribbon portion from the second ribbon portion, exposing the first tapered edge and the second tapered edge to a second etchant.

9. A method of manufacturing a glass ribbon comprising:

forming an initial groove at one or more of a first major surface of the glass ribbon or a second major surface of the glass ribbon, the initial groove formed between a first ribbon portion of the glass ribbon and a second ribbon portion of the glass ribbon; and

etching the glass ribbon to reduce a thickness of the glass ribbon and separate the first ribbon portion from the second ribbon portion along the initial groove such that a first tapered edge is formed at the first ribbon portion and a second tapered edge is formed at the second ribbon portion.

10. The method of claim 9, wherein the forming the initial groove comprises perforating the first major surface at a plurality of locations between the first ribbon portion and the second ribbon portion.

11. The method of claim 9, wherein the forming the initial groove comprises scoring the first major surface between the first ribbon portion and the second ribbon portion.

12. The method of any one of claims 9-11, wherein the etching the glass ribbon comprises exposing the first major surface and the second major surface to an etchant for a period of time until the first ribbon portion is separated from the second ribbon

portion and a gap is formed between the first tapered edge of the first ribbon portion and the second tapered edge of the second ribbon portion.

13. The method of any one of claims 9-11, wherein the etching the glass ribbon comprises exposing the first major surface and the second major surface to an etchant and concluding an exposure of the first major surface and the second major surface to the etchant prior to the first ribbon portion separating from the second ribbon portion.

14. The method of claim 13, further comprising applying a mechanical force to the glass ribbon to separate the first ribbon portion from the second ribbon portion after concluding the exposure of the first major surface and the second major surface to the etchant.

15. A method of manufacturing a glass ribbon comprising:

masking a first major surface and a second major surface of the glass ribbon;

unmasking a first exposed region of the first major surface and a second exposed region of the second major surface;

forming an initial groove at one or more of the first exposed region or the second exposed region, the initial groove formed between a first ribbon portion of the glass ribbon and a second ribbon portion of the glass ribbon; and

etching the first exposed region and the second exposed region to separate the first ribbon portion from the second ribbon portion along the initial groove and form a first tapered edge at the first ribbon portion and a second tapered edge at the second ribbon portion.

16. The method of claim 15, wherein the unmasking the first exposed region and the second exposed region comprises directing a laser beam towards a mask covering the first exposed region and a second mask covering the second exposed region.

17. The method of claim 16, wherein the forming the initial groove comprises directing the laser beam towards the first exposed region to perforate the first exposed region at a plurality of locations.

18. The method of claim 16, wherein the forming the initial groove comprises scoring the first exposed region.

19. The method of any one of claims 15-18, further comprising maintaining an initial thickness of the glass ribbon such that the initial thickness of the glass ribbon, defined between the first major surface and the second major surface at a first location spaced a distance apart from the first exposed region and the second exposed region, prior to etching is substantially equal to a final thickness of the first ribbon portion, defined between the first major surface and the second major surface at the first location, after etching.

20. The method of claim 19, wherein the maintaining the initial thickness of the glass ribbon comprises maintaining the initial thickness within a range from about 20 μm to about 200 μm.

21. A glass ribbon comprising:

a first major surface extending along a first plane;

a second major surface extending along a second plane substantially parallel to the first plane, wherein a first thickness is defined between the first major surface and the second major surface along a thickness direction perpendicular to the first major surface, wherein the first thickness is within a range from about 25 μm to about 125 μm; and

an edge surface extending between the first plane and the second plane, the edge surface comprising a height in the thickness direction that is less than the first thickness.

22. The glass ribbon of claim 21, wherein the edge surface extends along an edge plane that is substantially perpendicular to the first plane, the edge surface spaced a first separating thickness from the first plane and a second separating thickness from the second plane.

23. The glass ribbon of claim 22, wherein the first separating thickness is substantially equal to the second separating thickness.

24. The glass ribbon of claim 21, wherein the edge surface is non-planar.

25. A glass ribbon comprising:

a first major surface extending along a first plane;

a second major surface extending along a second plane substantially parallel to the first plane, wherein a first thickness is defined between the first major surface and the second major surface along a thickness direction perpendicular to the first major surface, wherein the first thickness is within a range from about 25 μm to about 125 μm;

an edge surface extending between the first plane and the second plane along an edge plane that is substantially perpendicular to the first plane;

a first intermediate surface extending between a first outer edge of the first major surface and a first outer edge of the edge surface;

a second intermediate surface extending between a first outer edge of the second major surface and a second outer edge of the edge surface, wherein a first separating length between the first outer edge of the first major surface and the edge plane in a direction parallel to the first major surface is within a range from about 5 μm to about 85 μm and a first separating thickness between the first outer edge of the edge surface and the first plane along a direction parallel to the edge plane is within a range from about 25 μm to about 100 μm.

26. The glass ribbon of claim 25, wherein a second separating length between the first outer edge of the second major surface and the edge plane in a direction parallel to the second major surface is within a range from about 5 μm to about 85 μm.

27. The glass ribbon of claim 26, wherein the first separating length is substantially equal to the second separating length.

28. The glass ribbon of any one of claims 25-27, wherein a second separating thickness between the second outer edge of the edge surface and the second plane along the direction parallel to the edge plane is within a range from about 25 μm to about 100 μm.

29. The glass ribbon of claim 28, wherein the first separating thickness is substantially equal to the second separating thickness.

30. The glass ribbon of any one of claims 25-29, wherein the first intermediate surface is non-parallel with the second intermediate surface.

31. The glass ribbon of any one of claims 25-30, wherein the edge surface comprises a height in the thickness direction that is less than the first thickness.

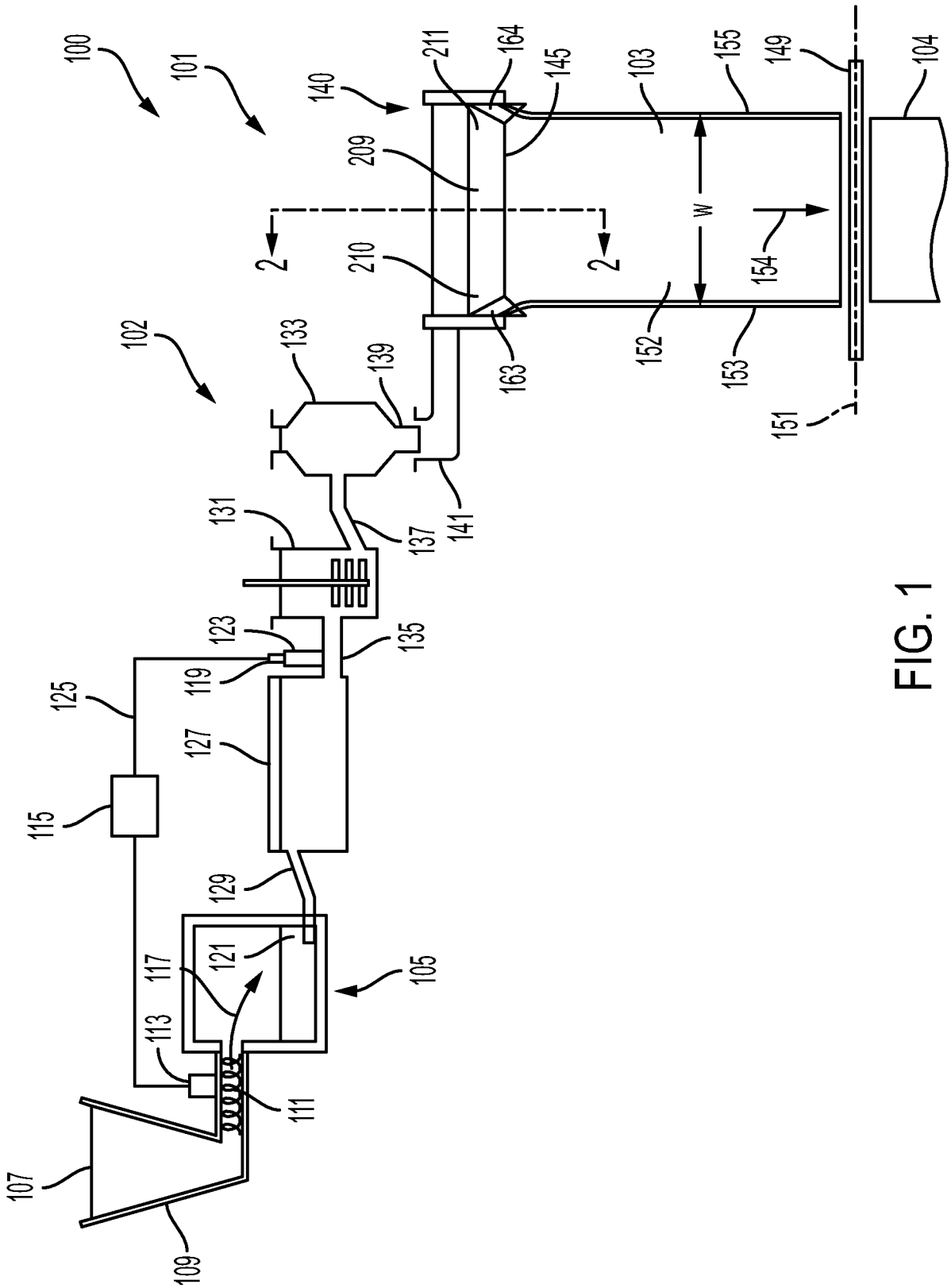
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FIG. 1

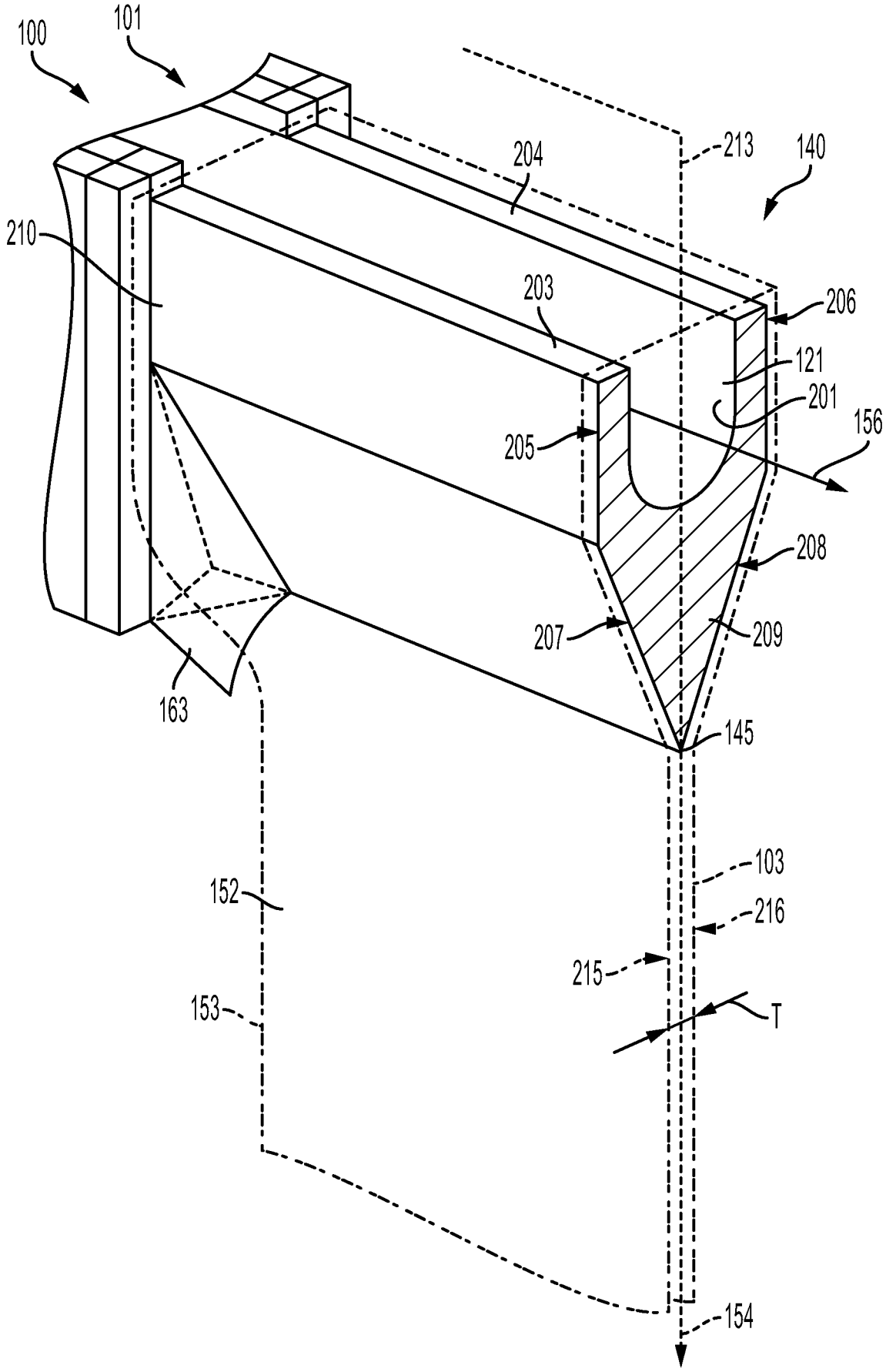
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FIG. 2

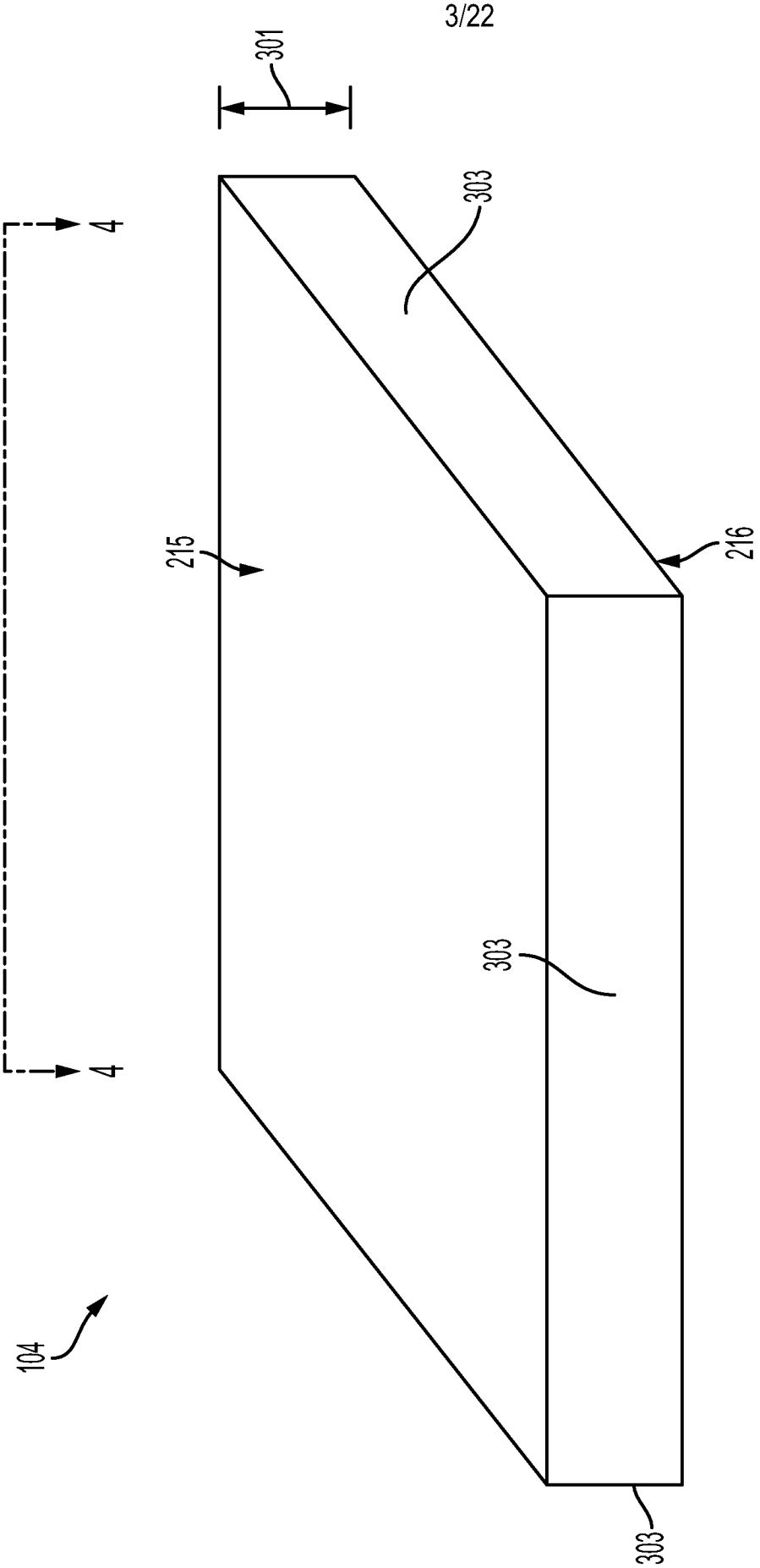

FIG. 3

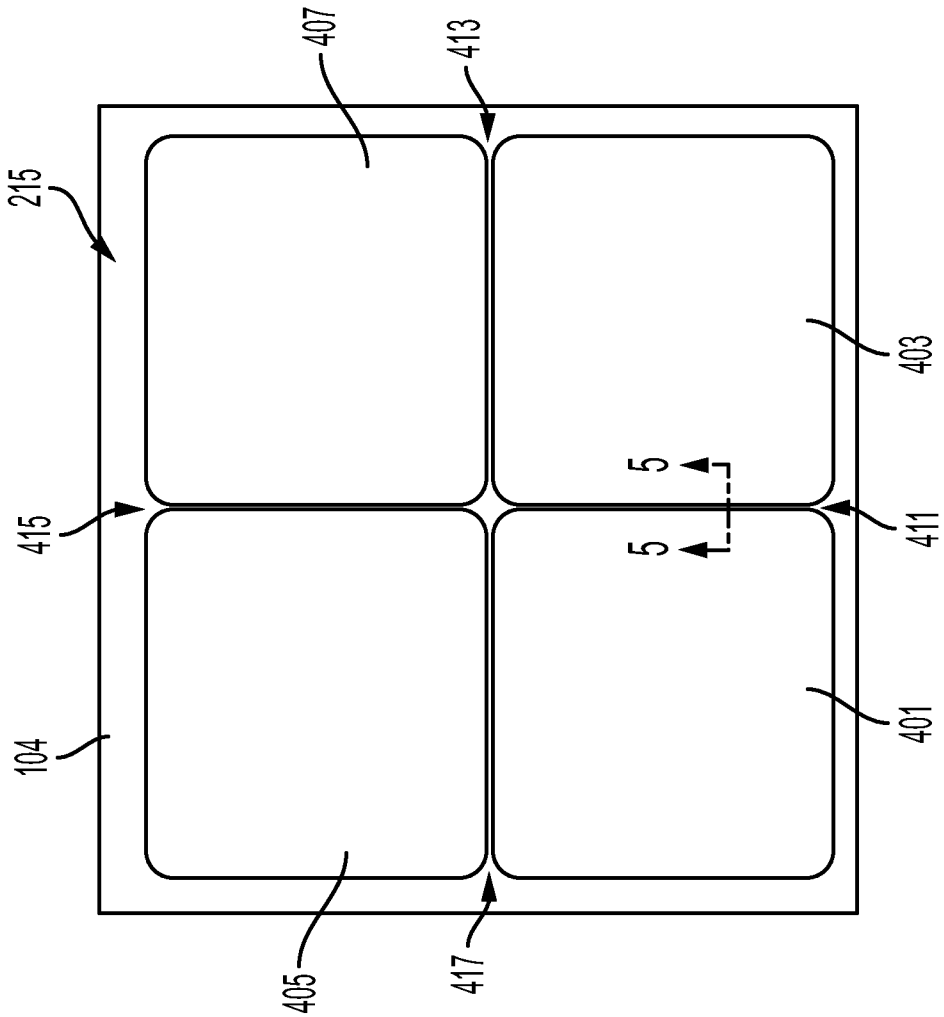

FIG. 4

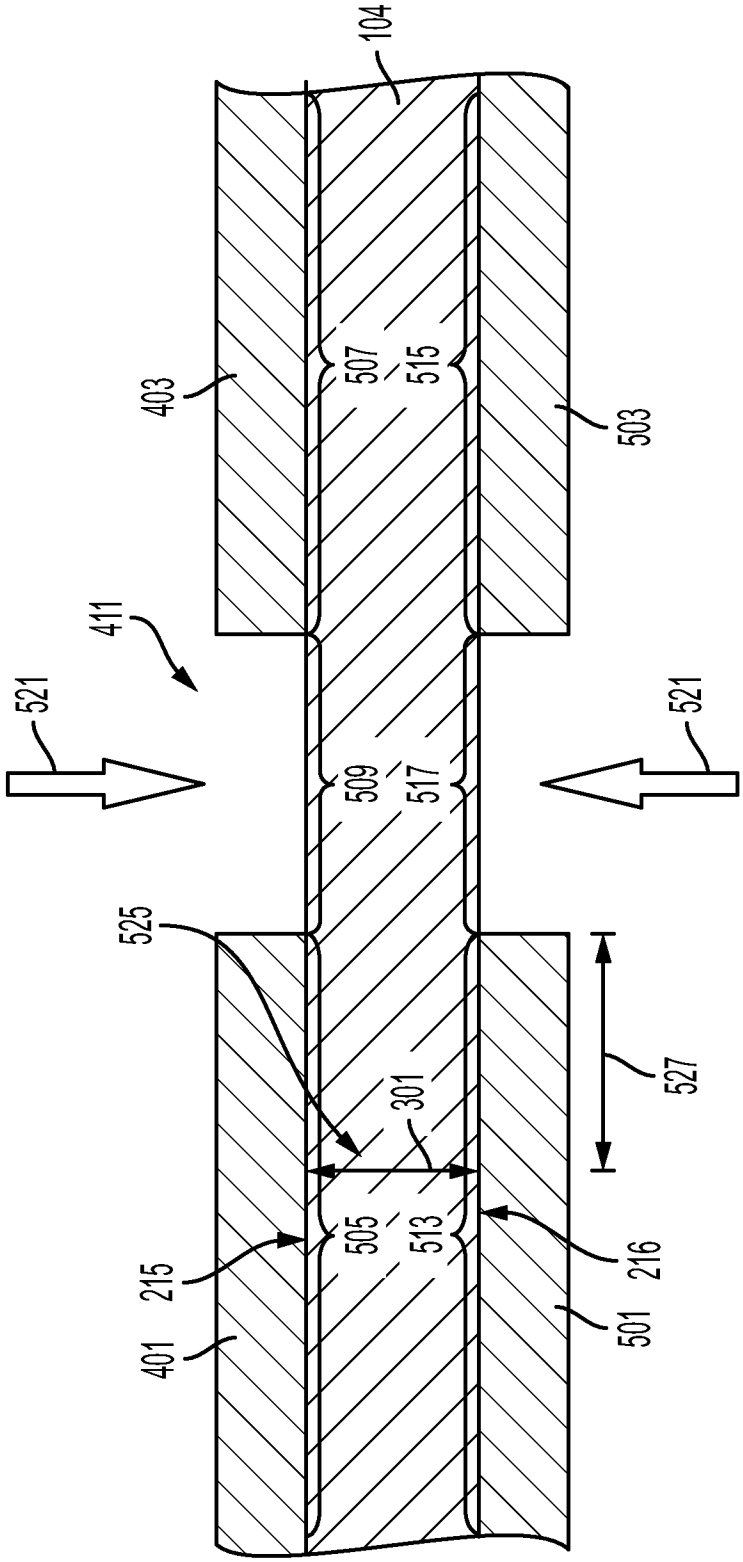
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FIG. 5

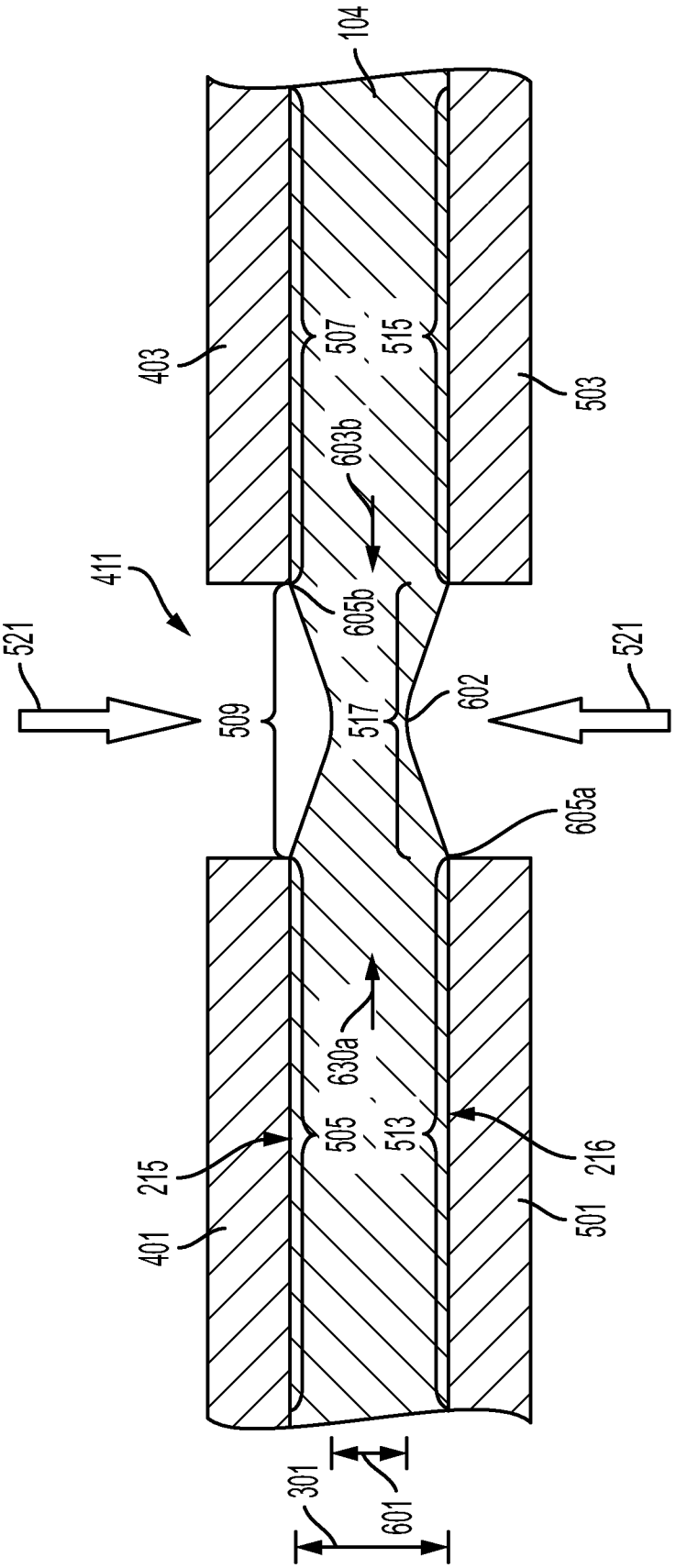
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FIG. 6

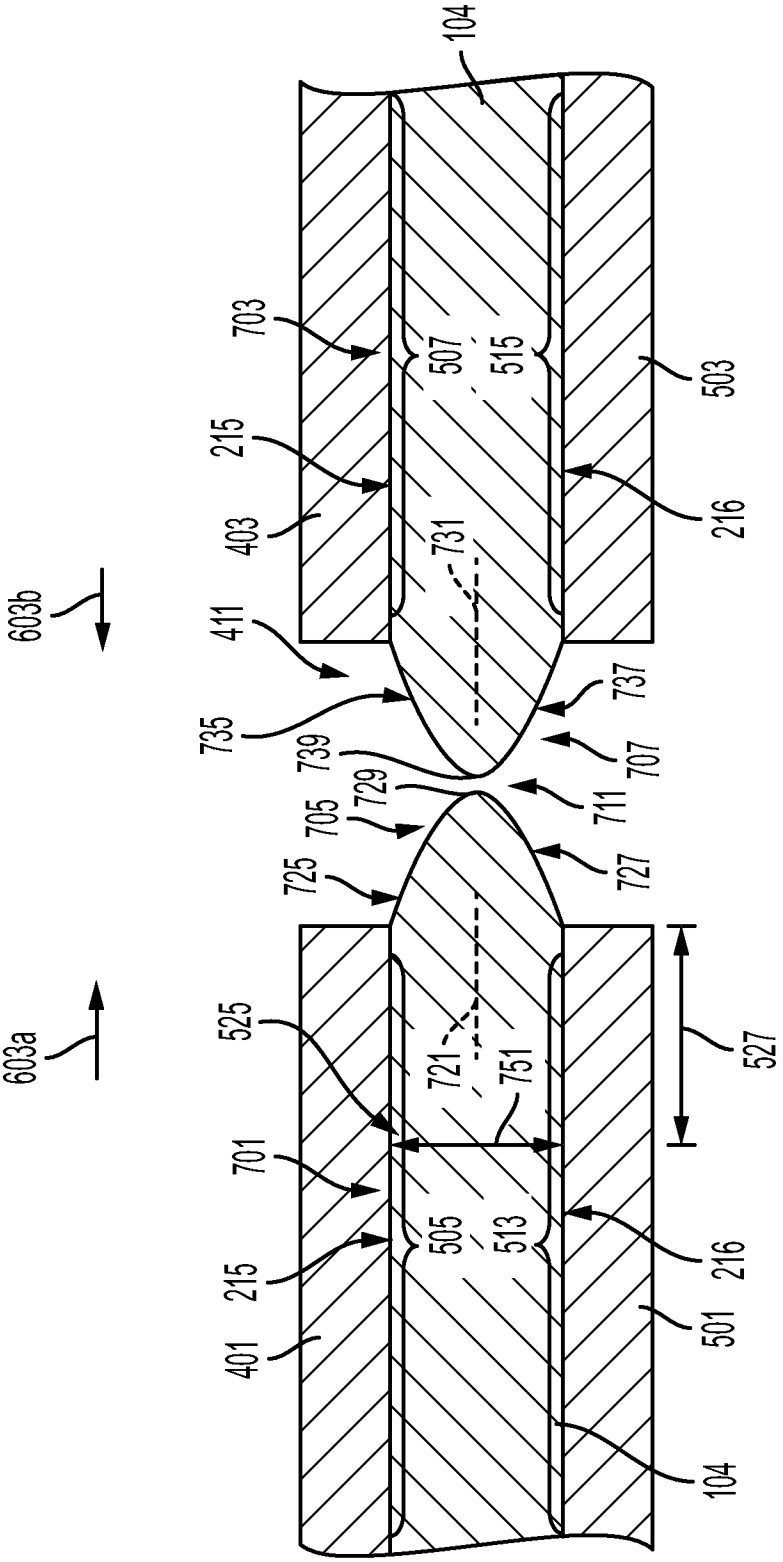
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FIG. 7

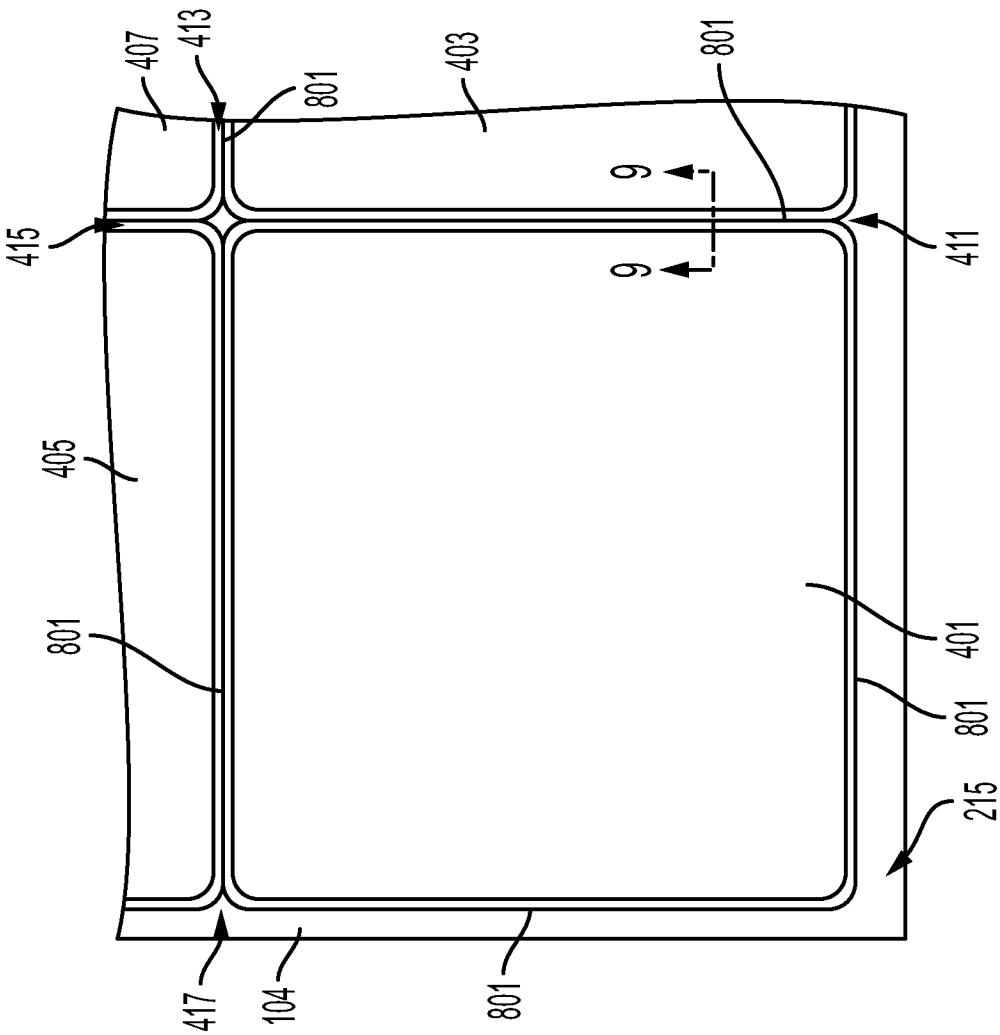

FIG. 8

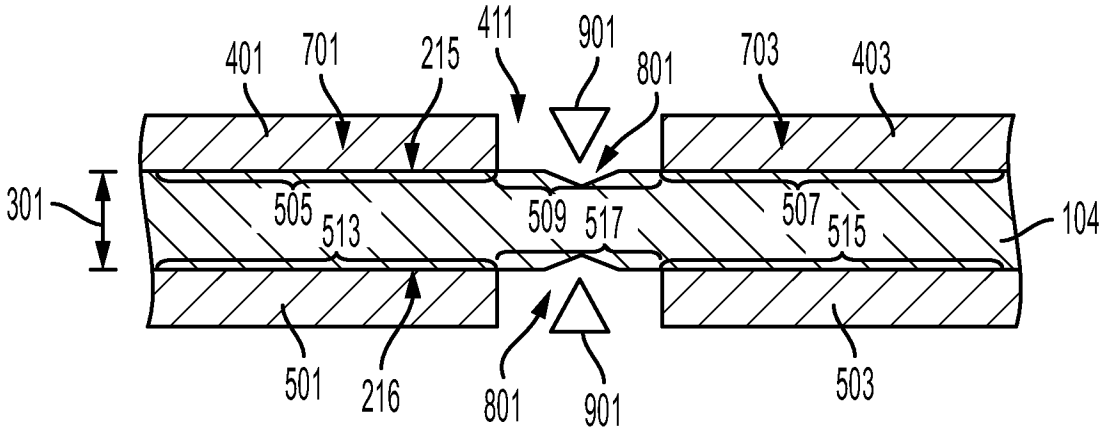

FIG. 9

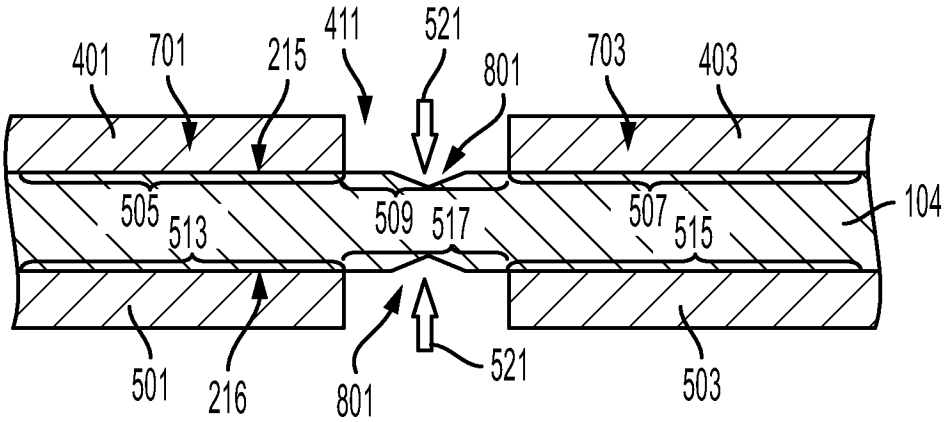

FIG. 10

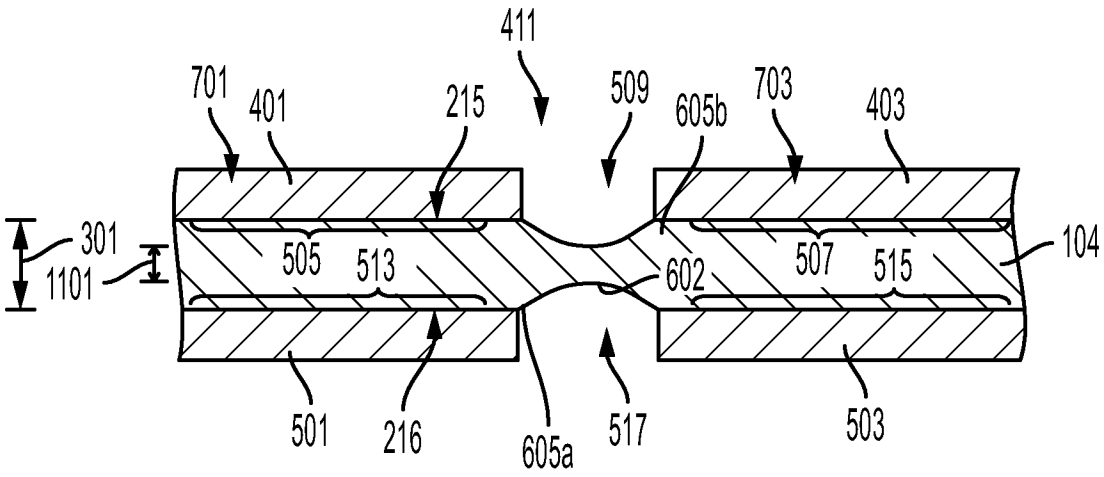

FIG. 11

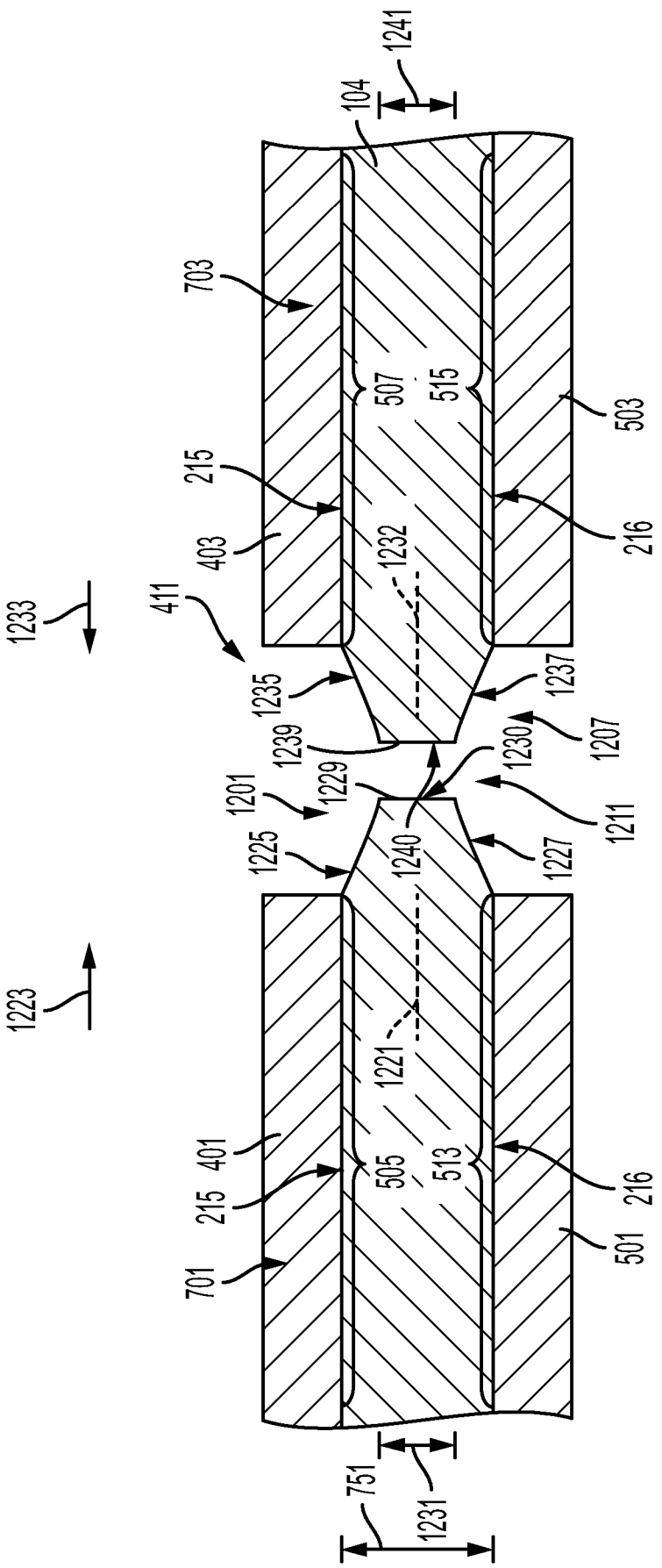
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FIG. 12

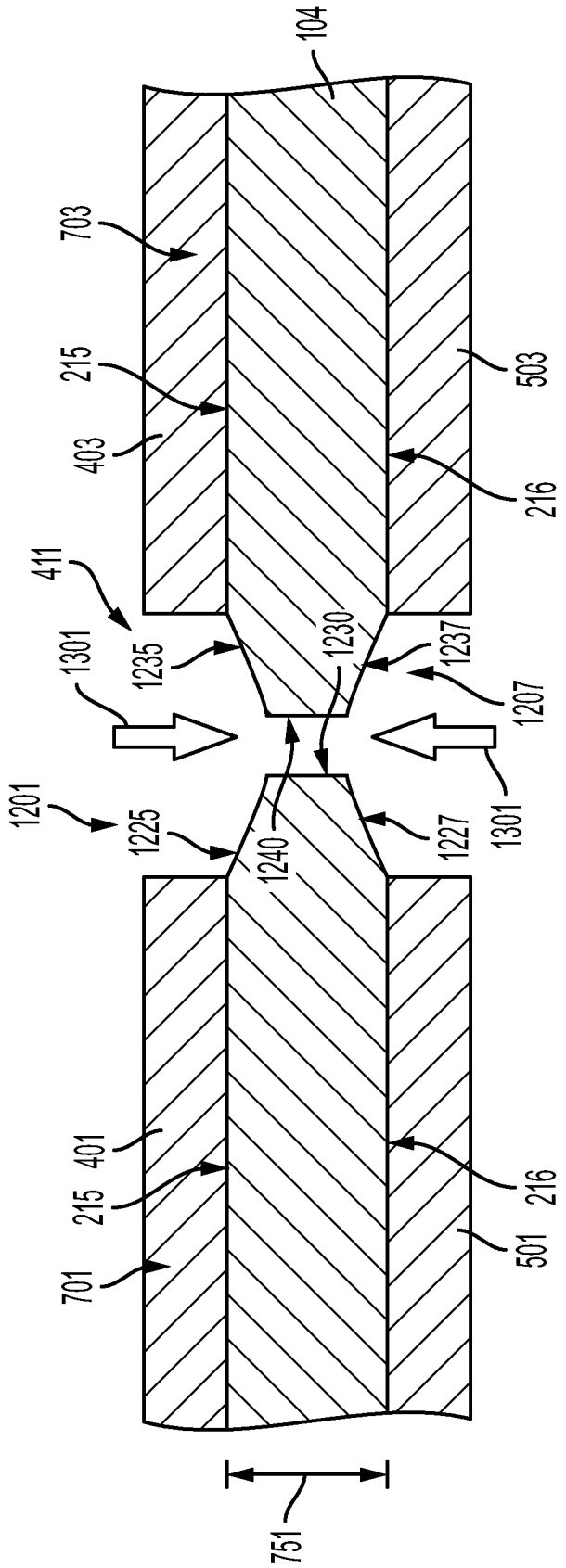
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FIG. 13

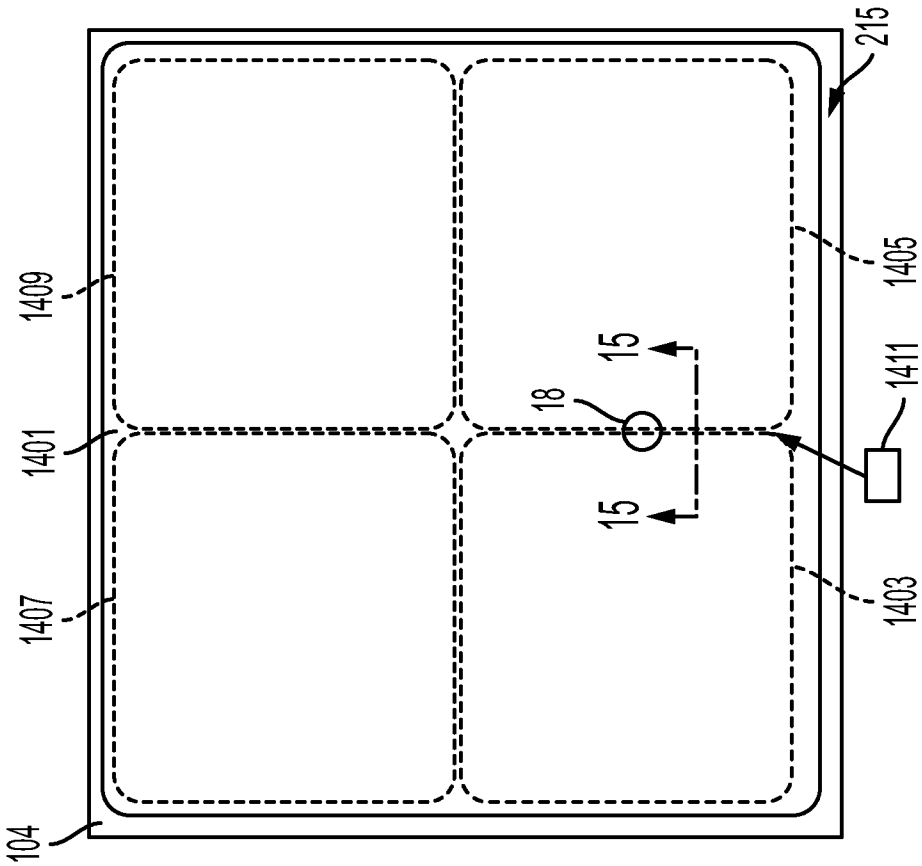

FIG. 14

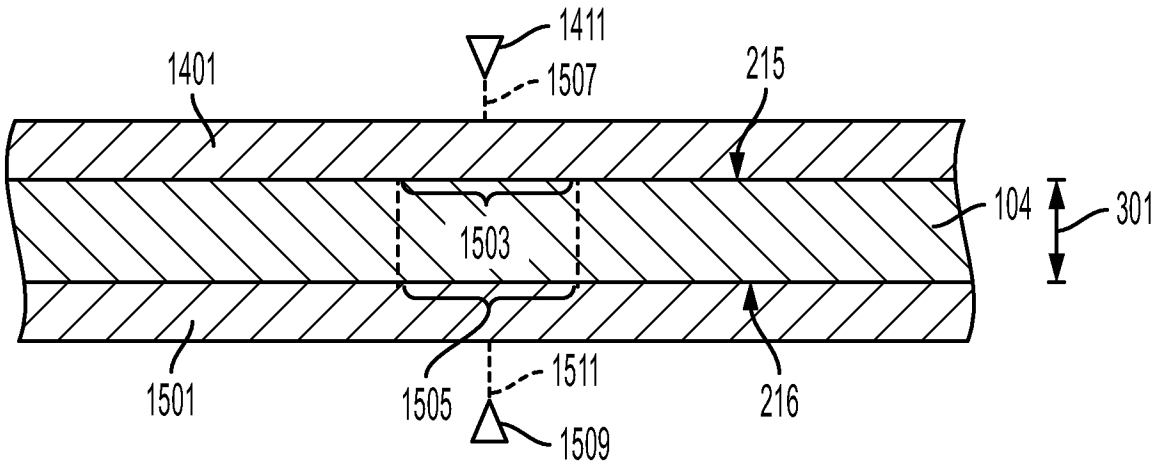
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FIG. 15

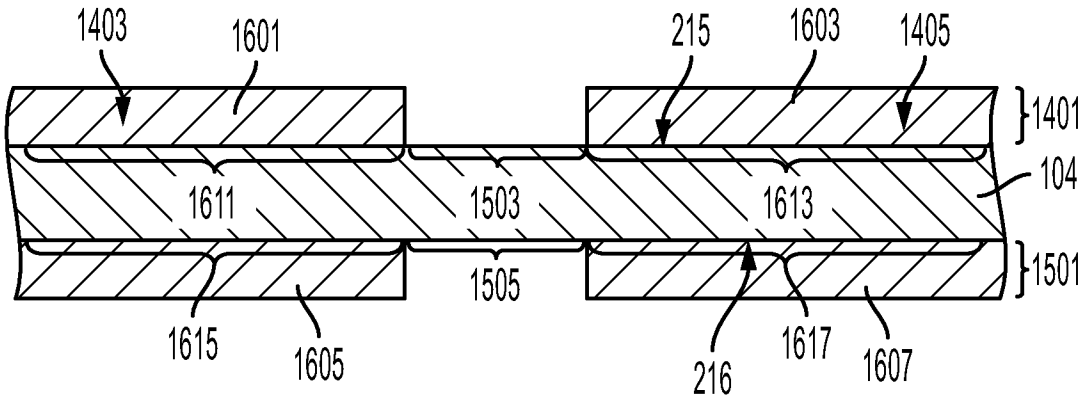
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FIG. 16

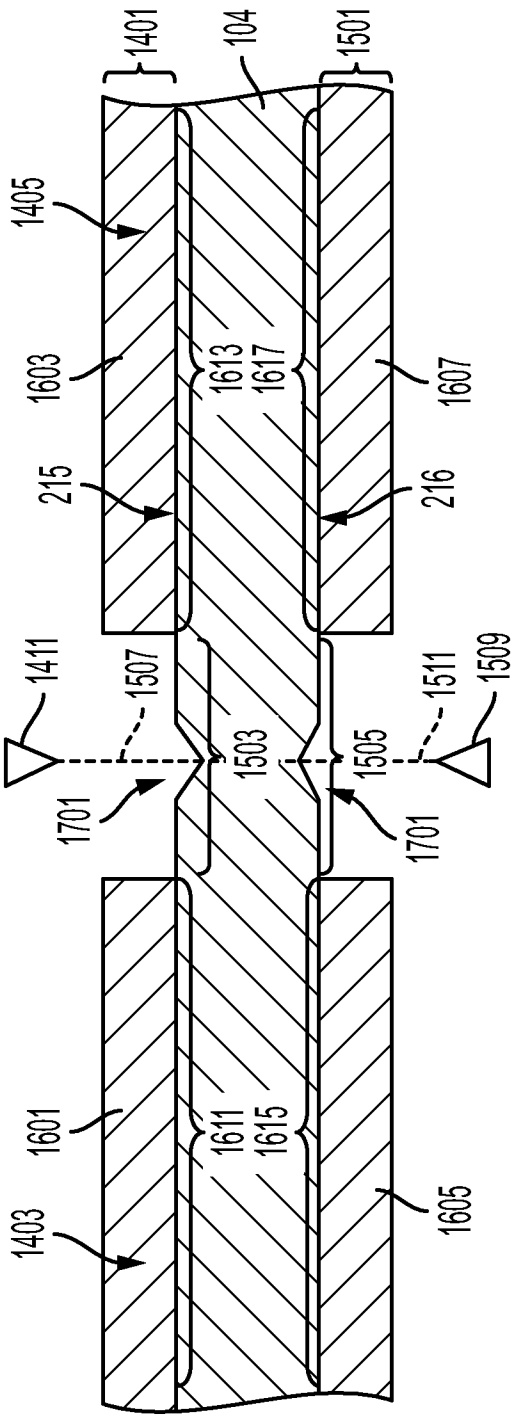
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FIG. 17

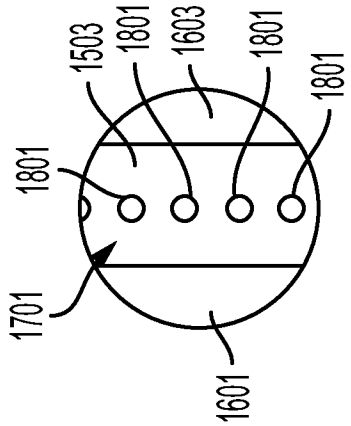
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FIG. 18

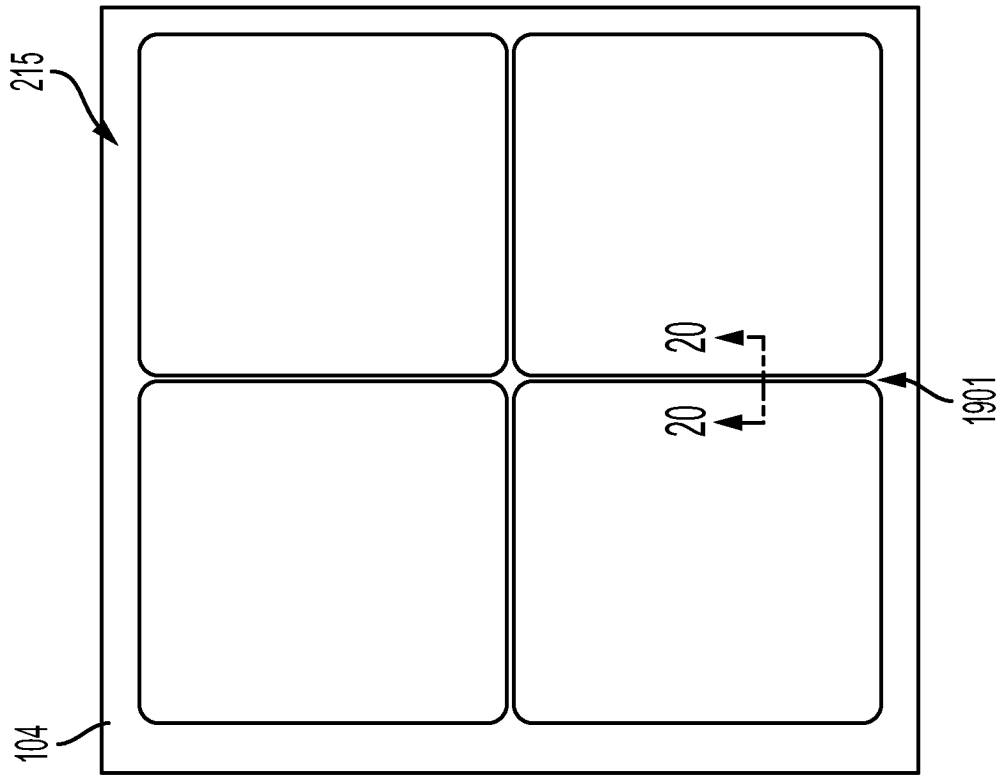

FIG. 19

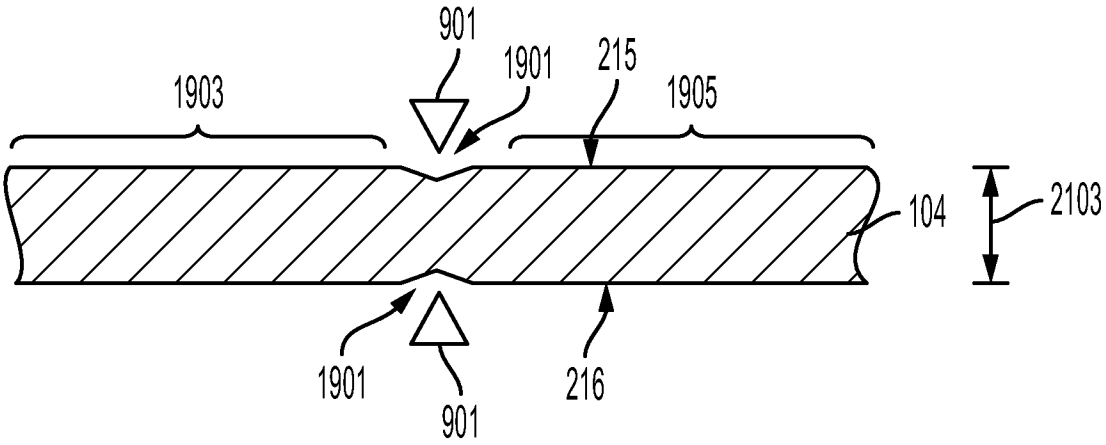

FIG. 20

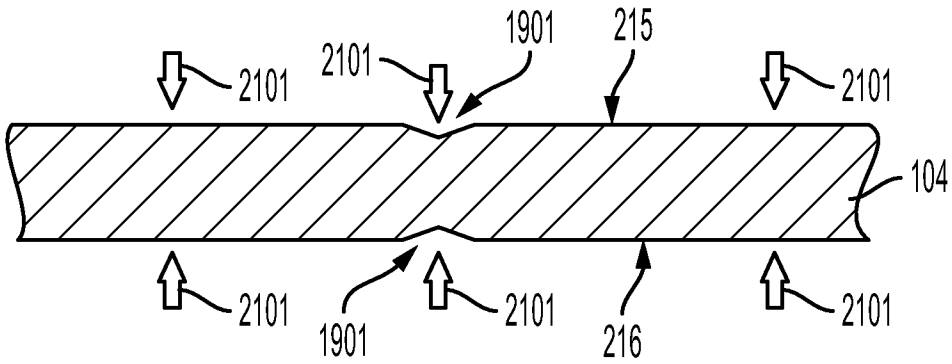

FIG. 21

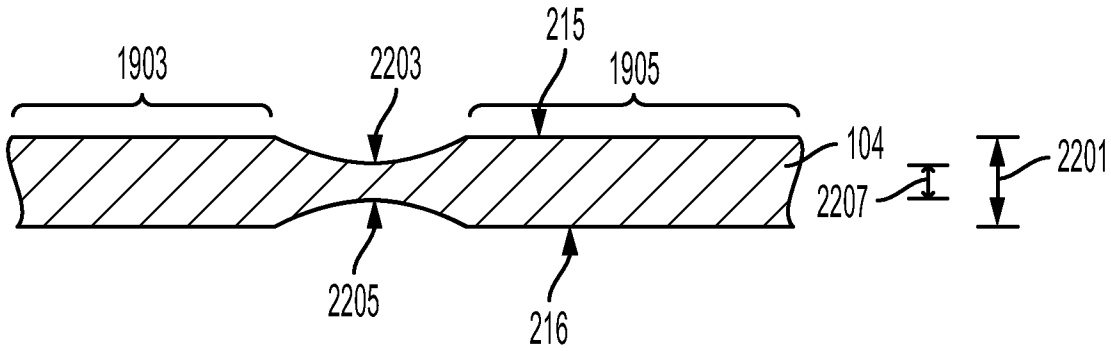

FIG. 22

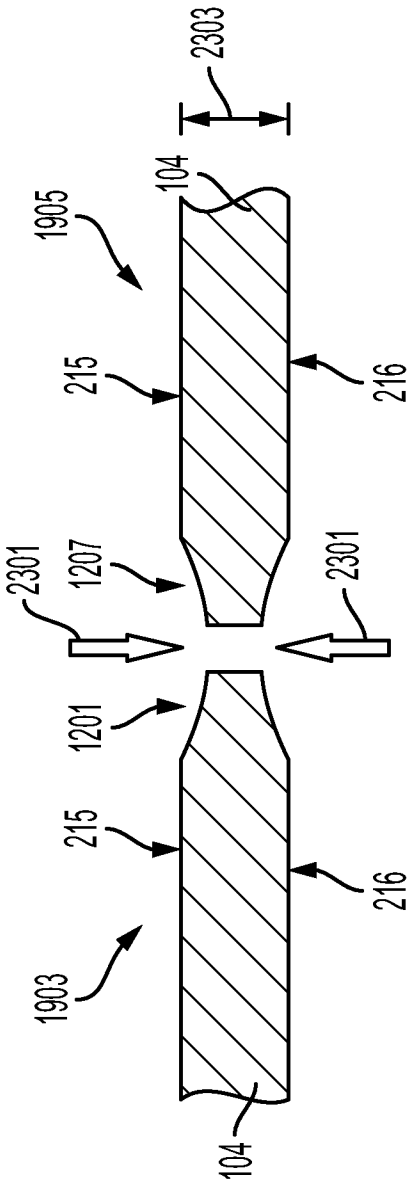
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FIG. 23

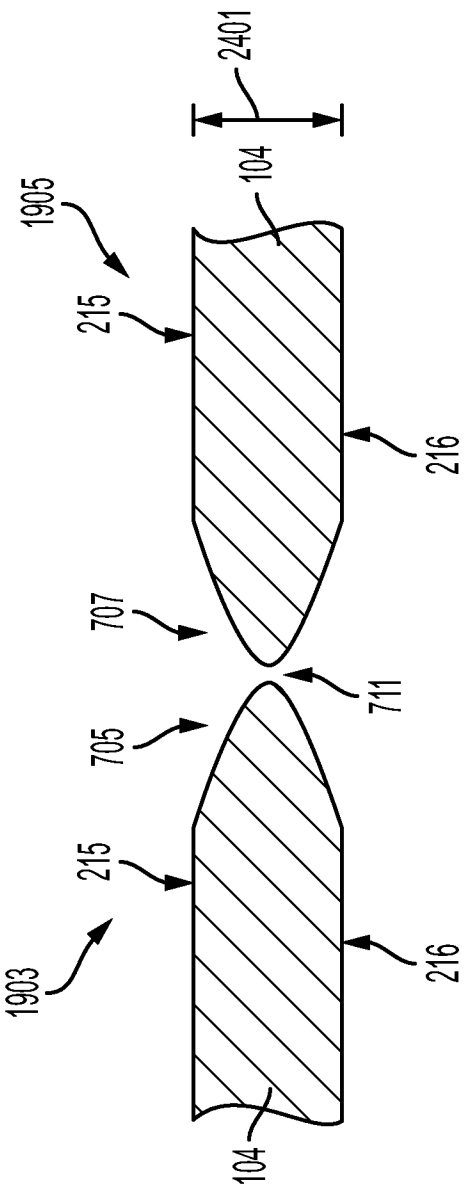
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FIG. 24

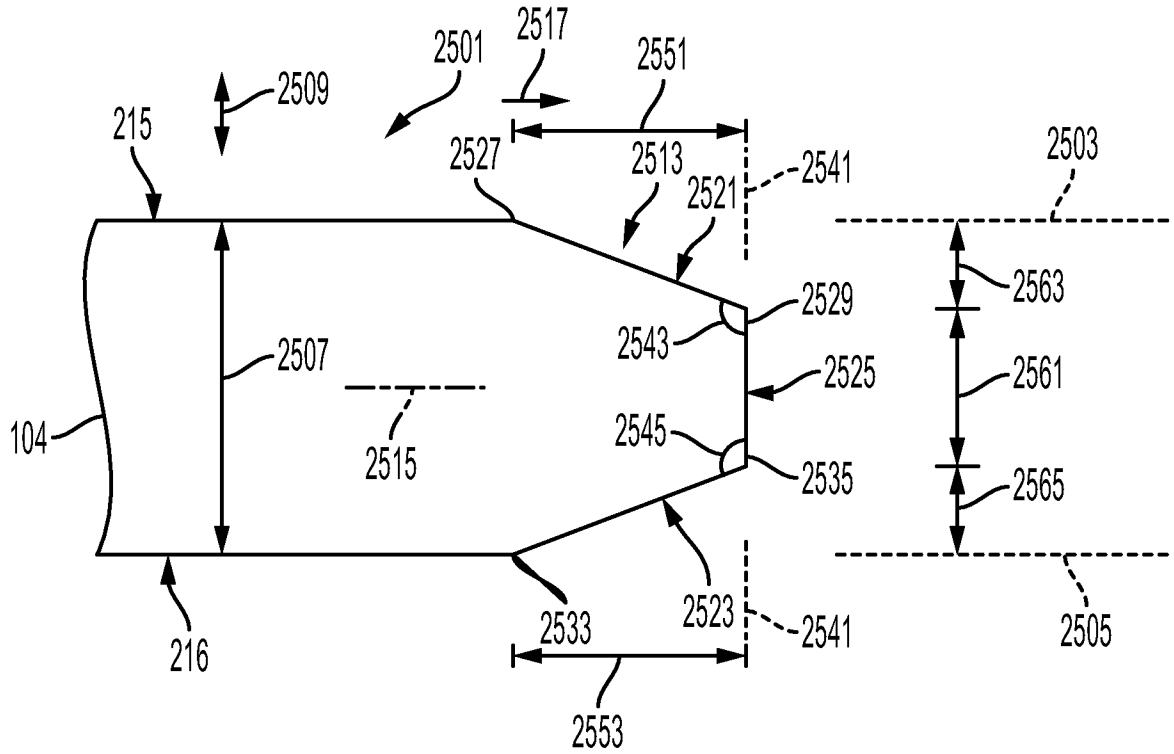
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FIG. 25

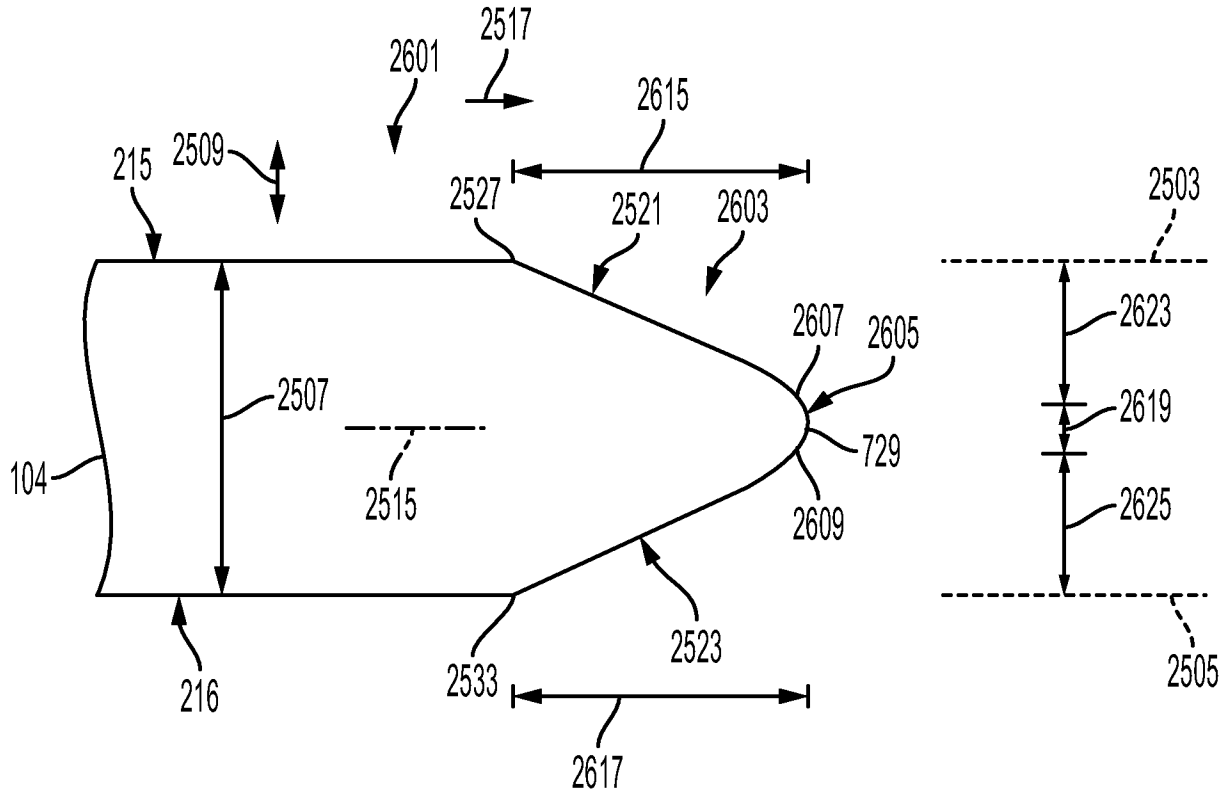
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FIG. 26

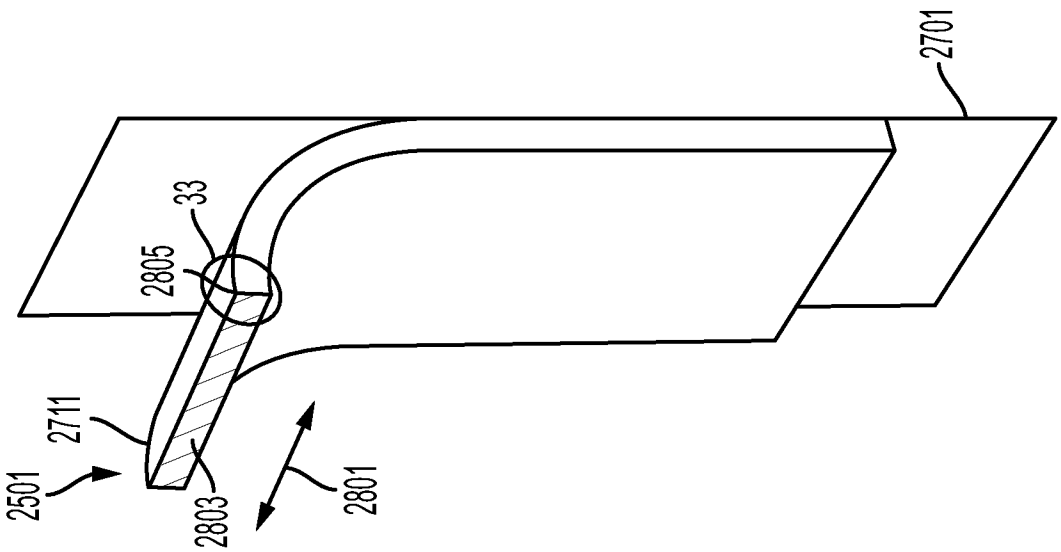
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FIG. 28

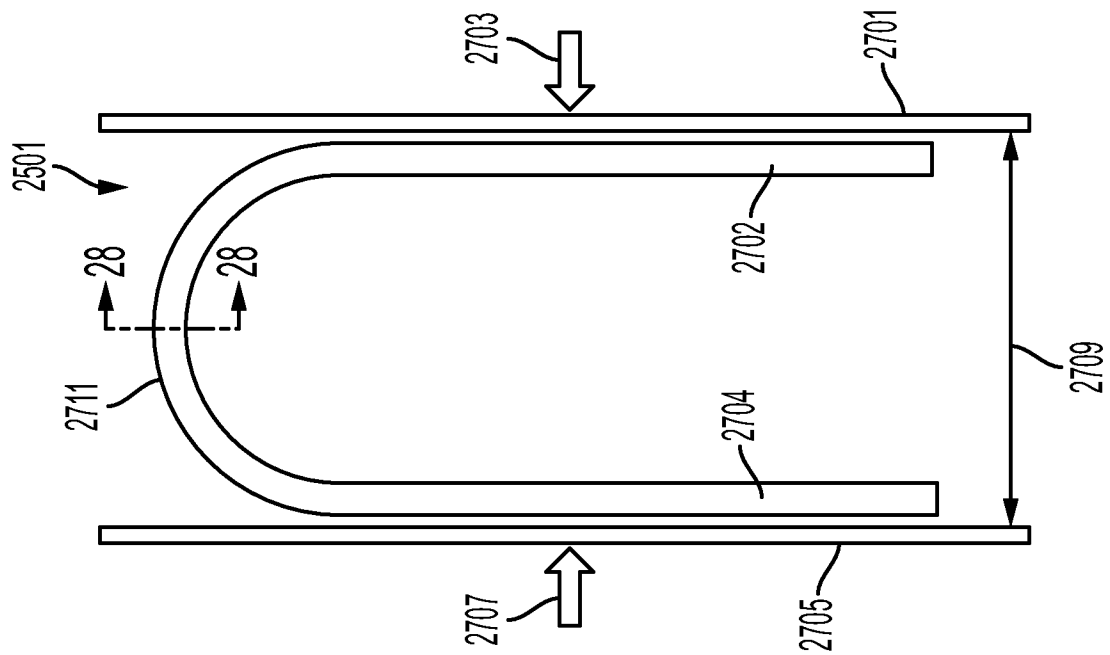
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FIG. 27

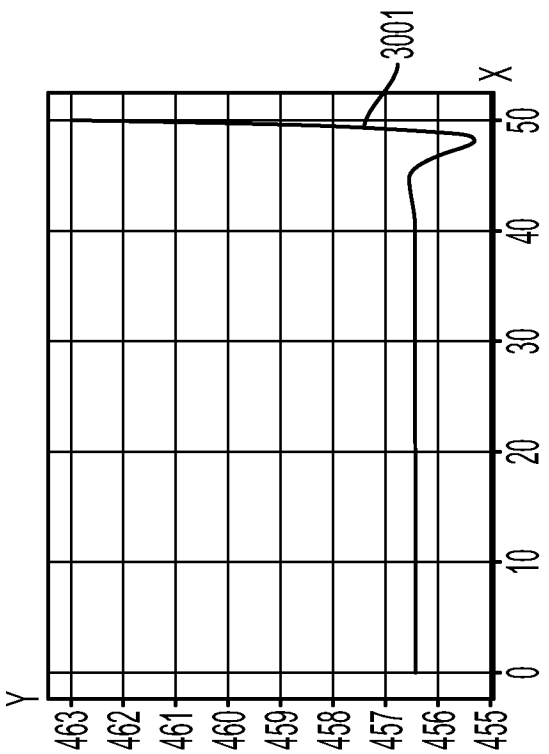

FIG. 30

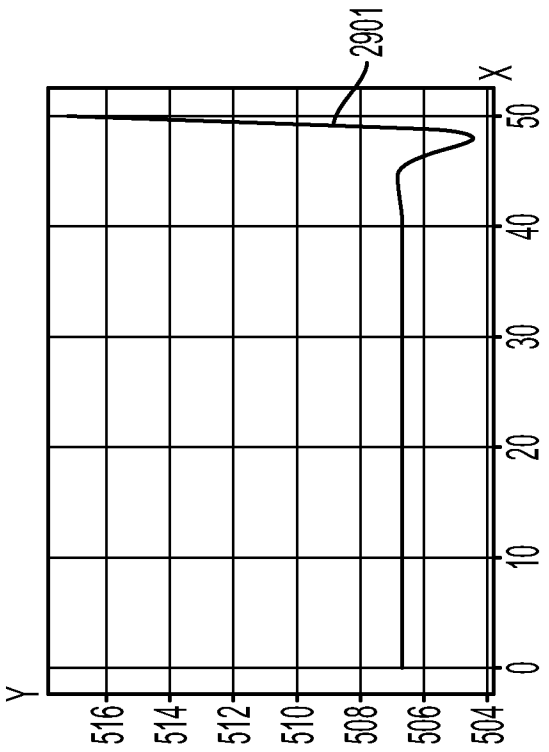

FIG. 29

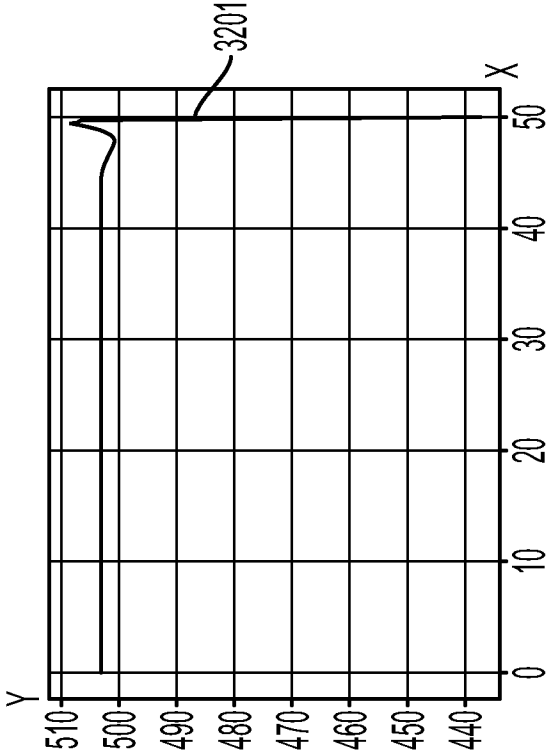

FIG. 32

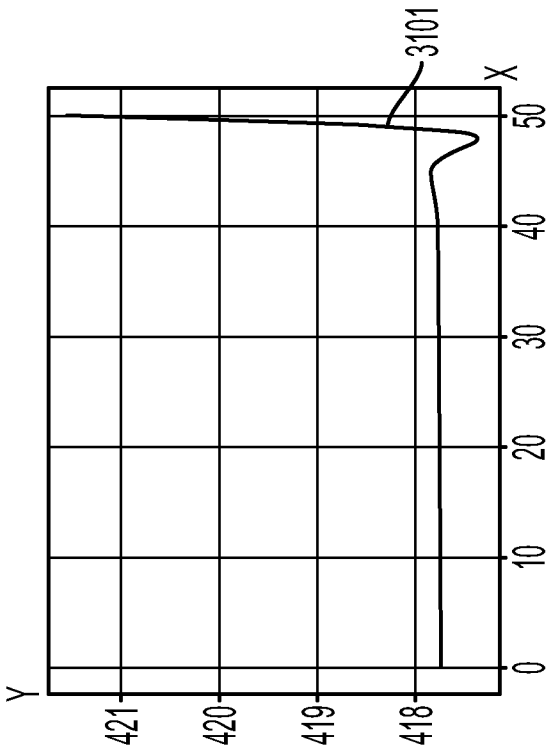

FIG. 31

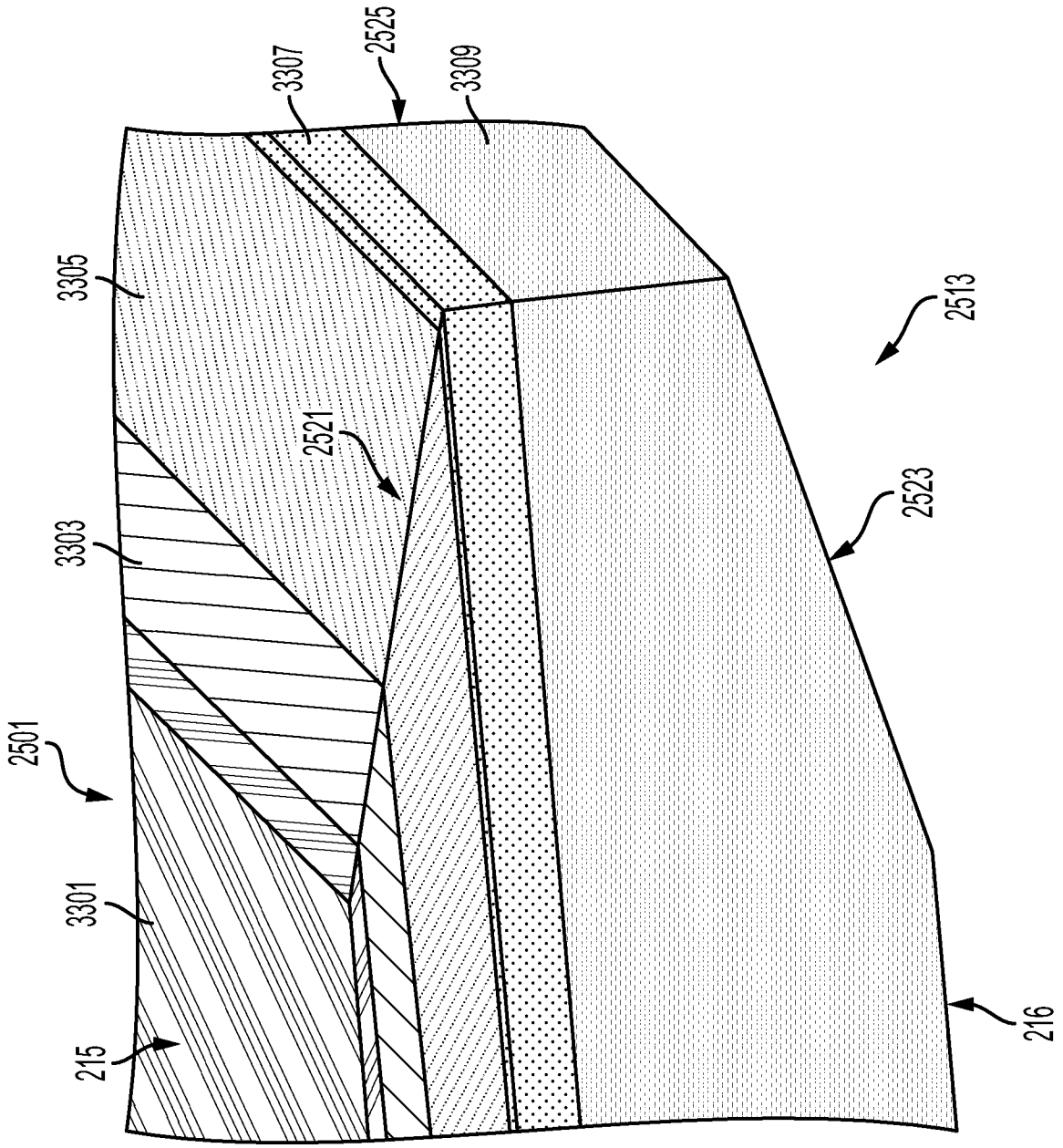

FIG. 33

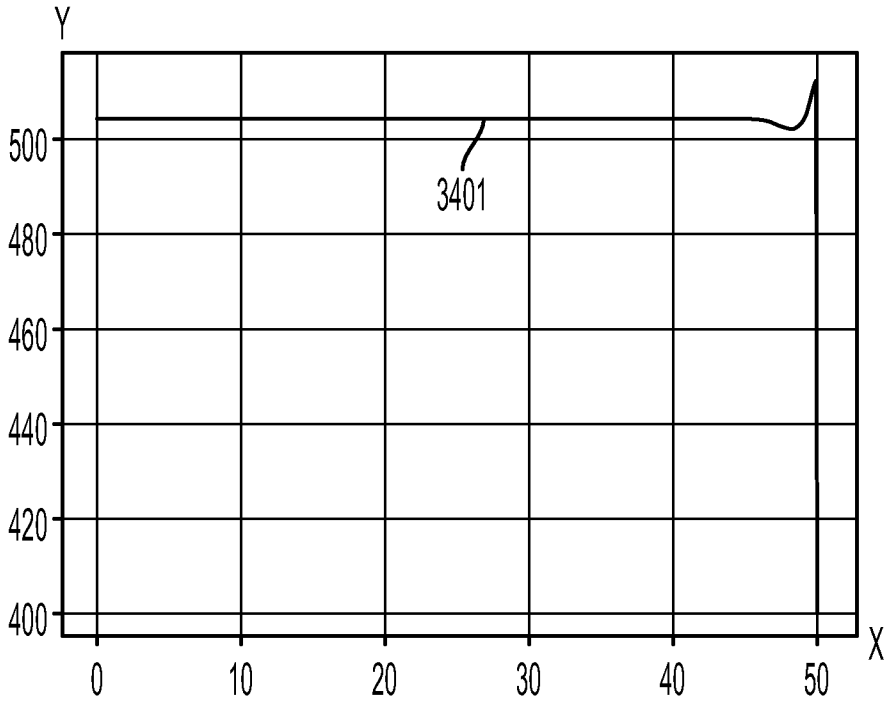
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FIG. 34

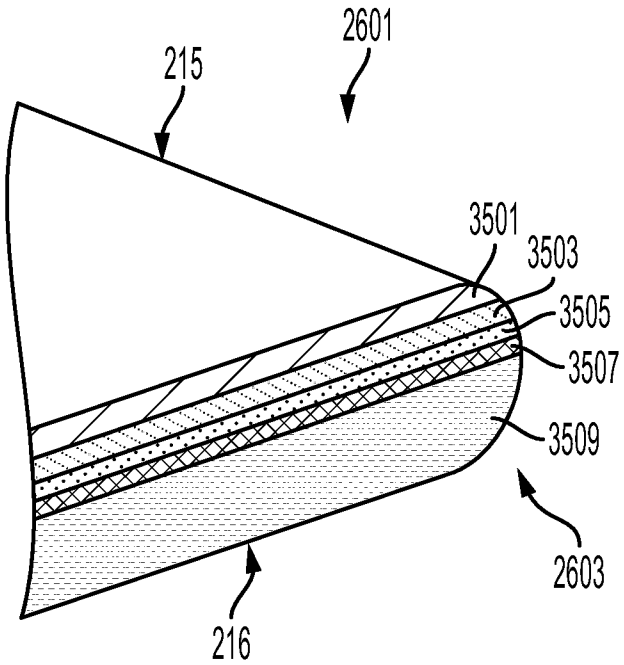
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FIG. 35

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/038591

A. CLASSIFICATION OF SUBJECT MATTER
INV. C03C21/00 C03C25/601 C03C15/00
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)
C03C

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	US 2016/221863 A1 (MURATA TAKASHI [JP] ET AL) 4 August 2016 (2016-08-04) paragraphs [0035], [0072], [0086] - paragraph [0087]; figure 4; example 4	1-8, 21-24
X	US 2016/127002 A1 (FUJII TATSUYA [JP]) 5 May 2016 (2016-05-05) paragraph [0049] - paragraph [0050]; figure 4(c); example 1	1-8
X	US 2013/034688 A1 (KOIKE AKIO [JP] ET AL) 7 February 2013 (2013-02-07) paragraph [0038] - paragraph [0051]; figure 3	21-31
X	JP 2012 246182 A (HOYA CORP) 13 December 2012 (2012-12-13) paragraph [0019] - paragraph [0034]	21-24

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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
4 September 2020	06/11/2020

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	Cristescu, Ioana

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2020/038591

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-8(completely); 21-31(partially)

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2020/038591

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2016221863 A1	04-08-2016	CN 105263878 A	20-01-2016
		JP 6288499 B2	07-03-2018
		JP 2015091739 A	14-05-2015
		KR 20160106003 A	09-09-2016
		US 2016221863 A1	04-08-2016
		WO 2015050054 A1	09-04-2015
US 2016127002 A1	05-05-2016	CN 101903301 A	01-12-2010
		CN 102701596 A	03-10-2012
		EP 2233447 A1	29-09-2010
		JP 5356576 B2	04-12-2013
		JP 5775056 B2	09-09-2015
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FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-8(completely); 21-31(partially)

A method of manufacturing a glass ribbon comprising: masking a first region and a second region of a first major surface of the glass ribbon, such that the first major surface comprises a first exposed region between the first region and the second region;masking a third region and a fourth region of a second major surface of the glass ribbon, such that the second major surface comprises a second exposed region between the third region and the fourth region; and etching the first exposed region and the second exposed region to separate a first ribbon portion, comprising the first region and the third region, from a second ribbon portion, comprising the second region and the fourth region, and form a first tapered edge at the first ribbon portion and a second tapered edge at the second ribbon portion.

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2. claims: 9-20(completely); 21-31(partially)

A method of manufacturing a glass ribbon comprising: forming an initial groove at one or more of a first major surface of the glass ribbon or a second major surface of the glass ribbon, the initial groove formed between a first ribbon portion of the glass ribbon and a second ribbon portion of the glass ribbon; and etching the glass ribbon to reduce a thickness of the glass ribbon and separate the first ribbon portion from the second ribbon portion along the initial groove such that a first tapered edge is formed at the first ribbon portion and a second tapered edge is formed at the second ribbon portion.
