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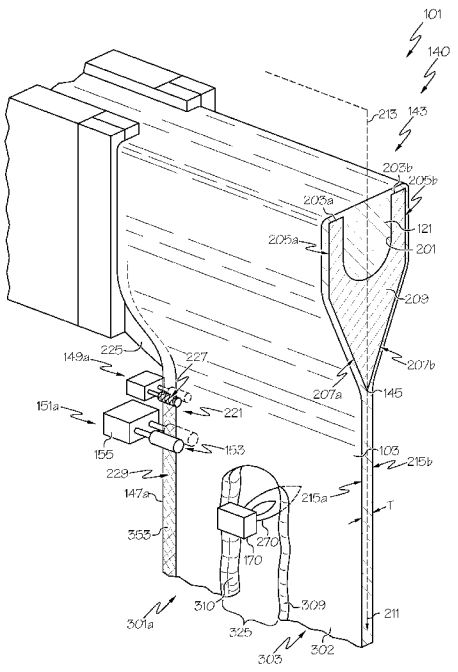

FIG. 2

(57) Abstract: A glass manufacturing apparatus can include a glass former to form a glass ribbon from a quantity of molten material and a cutting torch oriented to cut through the glass ribbon to separate a first edge portion from a central portion of the glass ribbon while the glass ribbon is drawn from the glass former. A method of manufacturing glass can include forming a glass ribbon from a quantity of molten material, drawing the glass ribbon in a draw direction, where the glass ribbon includes a pair of opposed edge portions and a central portion laterally spanning between the opposed edge portions, and separating a first edge portion of the pair of opposed edge portions from the central portion by cutting through the glass ribbon while the glass ribbon is being drawn in the draw direction.

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GLASS MANUFACTURING METHODS AND APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 62/314076 filed on March 28, 2016, the content of which is relied upon and incorporated herein by reference in its entirety.

FIELD

[0002] The present disclosure relates generally to methods and apparatus for manufacturing glass and, more particularly, to methods and apparatus for forming a glass ribbon from a quantity of molten material and separating an edge portion of the glass ribbon from a central portion of the glass ribbon by cutting through the glass ribbon while the glass ribbon is being drawn in a draw direction.

BACKGROUND

[0003] It is known to form a glass ribbon from a quantity of molten material. It is further known to separate an edge portion of the glass ribbon from a central portion of the glass ribbon.

SUMMARY

[0004] The following presents a simplified summary of the disclosure in order to provide a basic understanding of some exemplary embodiments described in the detailed description.

[0005] In some embodiments, a method of manufacturing glass can include forming a glass ribbon from a quantity of molten material, drawing the glass ribbon in a draw direction, where the glass ribbon includes a pair of opposed edge portions and a central portion laterally spanning between the opposed edge portions, and separating a first edge portion of the pair of opposed edge portions from the central portion by cutting through the glass ribbon while the glass ribbon is being drawn in the draw direction. Cutting through the glass ribbon can create a gap including a distance of from about 1 mm to about 20 mm between a cut edge of the central portion and a cut edge of the first edge portion.

[0006] In some embodiments, the gap can be created when the glass ribbon is in a viscous state prior to the glass ribbon transitioning to an elastic state.

[0007] In some embodiments, separating the first edge portion from the central portion can include cutting through the glass ribbon with a cutting torch.

[0008] In some embodiments, cutting through the glass ribbon with a cutting torch can include contacting the glass ribbon with a flame produced by the cutting torch.

[0009] In some embodiments, the method can further include separating a second edge portion of the pair of opposed edge portions from the central portion by cutting through the glass ribbon with another cutting torch while the glass ribbon is being drawn in the draw direction.

[0010] In some embodiments, cutting through the glass ribbon with the other cutting torch can create another gap including a distance of from about 1 mm to about 20 mm between another cut edge of the central portion and a cut edge of the second edge portion.

[0011] In some embodiments, cutting through the glass ribbon can provide the cut edge of the central portion with a cut edge bead including a thickness that is greater than a thickness of an interior portion of the central portion of the glass ribbon.

[0012] In some embodiments, the method can further include removing the cut edge bead from the interior portion of the central portion to provide a trimmed central portion.

[0013] In some embodiments, each of the opposed edge portions can include an outer edge bead including a thickness that is greater than a thickness of an interior portion of the central portion of the glass ribbon.

[0014] In some embodiments, cutting through the glass ribbon can provide the cut edge of the central portion with a cut edge bead including a thickness that is greater than the thickness of the outer edge bead of the first edge portion of the opposed edge portions.

[0015] In some embodiments, the method can further include separating a glass sheet from the central portion of the glass ribbon along a separation path that is transverse to the draw direction of the glass ribbon.

[0016] In some embodiments, cutting through the glass ribbon can provide the cut edge of the central portion with a cut edge bead including a thickness that is

greater than a thickness of an interior portion of the central portion of the glass ribbon. The glass sheet can include the cut edge bead, and the method can further include removing the cut edge bead from the glass sheet to provide a trimmed glass sheet.

[0017] In some embodiments, the glass ribbon can include a first cladding layer on a first major surface of the glass ribbon and a second cladding layer on a second major surface of the glass ribbon, and separating the first edge portion from the central portion can further include cutting through the first cladding layer and the second cladding layer while the glass ribbon is being drawn in the draw direction.

[0018] In some embodiments, separating the first edge portion from the central portion can include cutting through the first cladding layer and the second cladding layer with a cutting torch.

[0019] In some embodiments, cutting through the first cladding layer and the second cladding layer with a cutting torch can include contacting at least one of the first cladding layer and the second cladding layer with a flame produced by the cutting torch.

[0020] In some embodiments, cutting through the glass ribbon, the first cladding layer, and the second cladding layer can provide the cut edge of the central portion of the glass ribbon with a cut edge bead including a thickness that is greater than a thickness of an interior portion of the central portion of the glass ribbon.

[0021] In some embodiments, cutting through the glass ribbon, the first cladding layer, and the second cladding layer can provide the cut edge of the central portion of the glass ribbon with a cut edge bead that is encapsulated by at least one of the first cladding layer and the second cladding layer.

[0022] In some embodiments, a glass manufacturing apparatus can include a glass former to form a glass ribbon from a quantity of molten material and a cutting torch oriented to cut through the glass ribbon to separate a first edge portion from a central portion of the glass ribbon while the glass ribbon is drawn from the glass former.

[0023] In some embodiments, the glass manufacturing apparatus can further include another cutting torch oriented to cut through the glass ribbon to separate a

second edge portion from the central portion of the glass ribbon while the glass ribbon is drawn from the glass former.

[0024] In some embodiments, the cutting torch can be oriented to direct a flame from the cutting torch to contact a glass ribbon being drawn from the glass former.

[0025] The above embodiments are exemplary and can be provided alone or in any combination with any one or more embodiments provided herein without departing from the scope of the disclosure. Moreover, it is to be understood that both the foregoing general description and the following detailed description present embodiments of the present disclosure, and are intended to provide an overview or framework for understanding the nature and character of the embodiments as they are described and claimed. The accompanying drawings are included to provide a further understanding of the embodiments, and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments of the disclosure, and together with the description, serve to explain the principles and operations thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] These and other features, embodiments, and advantages of the present disclosure can be further understood when read with reference to the accompanying drawings:

[0027] FIG. 1 illustrates a schematic view of an exemplary glass manufacturing apparatus in accordance with embodiments disclosed herein;

[0028] FIG. 2 illustrates a cross-sectional perspective view of the exemplary glass manufacturing apparatus along line **2-2** of **FIG. 1**;

[0029] FIG. 3 illustrates another schematic view of the exemplary glass manufacturing apparatus of **FIG. 1**;

[0030] FIG. 4 illustrates a cross-sectional view of the exemplary glass manufacturing apparatus along line **4-4** of **FIG. 3**;

[0031] FIG. 5 illustrates a cross-sectional view of the exemplary glass manufacturing apparatus of another embodiment along line **4-4** of **FIG. 3**;

[0032] **FIG. 6** is a cross-sectional view of the exemplary glass manufacturing apparatus, according to the embodiment of **FIG. 4**, along line **6-6** of **FIG. 3**, illustrating initiation of a method of separating a first edge portion of a pair of opposed edge portions from a central portion of a glass ribbon;

[0033] **FIG. 7** is another cross-sectional view of the method after initiating separation of **FIG. 6**, wherein a bulge has developed in the glass ribbon;

[0034] **FIG. 8** is another cross-sectional view of the method after developing the bulge of **FIG. 7**, wherein cut edge beads have begun to develop;

[0035] **FIG. 9** is another cross-sectional view similar to **FIG. 8** after the cut edge beads have developed with a gap formed between the developed edge beads;

[0036] **FIG. 10** is a cross-sectional view of the exemplary glass manufacturing apparatus, according to the embodiment of **FIG. 5**, along line **6-6** of **FIG. 3** illustrating initiation of a method of separating a first edge portion of a pair of opposed edge portions from a central portion of a glass ribbon;

[0037] **FIG. 11** is another cross-sectional view of the method after initiating separation of **FIG. 10**, wherein a bulge has developed in the glass ribbon;

[0038] **FIG. 12** is another cross-sectional view of the method after developing the bulge of **FIG. 11**, wherein cut edge beads have begun to develop;

[0039] **FIG. 13** is another cross-sectional view similar to **FIG. 12** after the cut edge beads have developed with a gap formed between the developed edge beads;

[0040] **FIG. 14** illustrates an embodiment of a cross-sectional view of the exemplary glass manufacturing apparatus, according to the embodiment of **FIG. 4**, along line **14-14** of **FIG. 3**; and

[0041] **FIG. 15** illustrates another embodiment of a cross-sectional view of the exemplary glass manufacturing apparatus, according to the embodiment of **FIG. 5**, along line **14-14** of **FIG. 3**.

DETAILED DESCRIPTION

[0042] Apparatus and methods will now be described more fully hereinafter with reference to the accompanying drawings in which exemplary embodiments of the disclosure 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.

[0043] Glass sheets are commonly fabricated by flowing molten glass to a forming body whereby a glass ribbon may be formed by a variety of ribbon forming processes including, float, slot draw, down-draw, fusion down-draw, up-draw, press roll or any other forming processes. The glass ribbon from any of these processes may then be subsequently divided to provide one or more glass sheets suitable for further processing into a desired application, including but not limited to, a display application. For example, the one or more glass sheets can be used in a variety of display applications, including liquid crystal displays (LCDs), electrophoretic displays (EPD), organic light emitting diode displays (OLEDs), plasma display panels (PDPs), or the like.

[0044] **FIG. 1** schematically illustrates an exemplary glass manufacturing apparatus **101** to form a glass ribbon **103**. For illustration purposes, the glass manufacturing apparatus **101** is illustrated as a fusion down-draw apparatus, although other glass manufacturing apparatus for up-draw, float, press rolling, slot draw, etc. may be provided in further embodiments. As illustrated, the glass manufacturing apparatus **101** can include 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**. 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**. A glass melt probe **119** can be used 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**.

[0045] The glass manufacturing apparatus **101** can also include 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** may be gravity fed from the melting vessel **105** to the fining vessel **127** by way of the first connecting conduit **129**. For example, gravity may act to drive the molten material **121** to pass through an interior pathway of the first connecting

conduit **129** from the melting vessel **105** to the fining vessel **127**. Within the fining vessel **127**, bubbles may be removed from the molten material **121** by various techniques.

[0046] The glass manufacturing apparatus **101** can further include a mixing chamber **131** that may be located downstream from the fining vessel **127**. The mixing chamber **131** can be used 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** may be coupled to the mixing chamber **131** by way of a second connecting conduit **135**. In some embodiments, molten material **121** may be gravity fed from the fining vessel **127** to the mixing chamber **131** by way of the second connecting conduit **135**. For instance, gravity may drive the molten material **121** to pass through an interior pathway of the second connecting conduit **135** from the fining vessel **127** to the mixing chamber **131**.

[0047] The glass manufacturing apparatus **101** can further include a delivery vessel **133** that may be located downstream from the mixing chamber **131**. The delivery vessel **133** can condition the molten material **121** to be fed into a glass former **140**. 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 glass former **140**. As shown, the mixing chamber **131** may be coupled to the delivery vessel **133** by way of a third connecting conduit **137**. In some embodiments, molten material **121** may be gravity fed from the mixing chamber **131** to the delivery vessel **133** by way of the third connecting conduit **137**. For instance, gravity may drive the molten material **121** to pass through an interior pathway of the third connecting conduit **137** from the mixing chamber **131** to the delivery vessel **133**.

[0048] As further illustrated, a delivery pipe **139** can be positioned to deliver molten material **121** to the glass former **140** of the glass manufacturing apparatus **101**. The glass former **140** may draw the molten material **121** into the glass ribbon **103** off of a root **145** of a forming vessel **143**. In the illustrated embodiment, the forming vessel **143** can be provided with an inlet **141** oriented to receive molten material **121** from the delivery pipe **139** of the delivery vessel **133**. A width "**W**" of the glass

ribbon **103** can extend between a first vertical edge **147a** of the glass ribbon **103** and a second vertical edge **147b** of the glass ribbon **103**.

[0049] FIG. 2 is a cross-sectional perspective view of the glass manufacturing apparatus **101** along line **2-2** of **FIG. 1**. As shown, the forming vessel **143** can include a trough **201** oriented to receive the molten material **121** from the inlet **141**. The forming vessel **143** can further include a forming wedge **209** including a pair of downwardly inclined converging surface portions **207a**, **207b** extending between opposed ends of the forming wedge **209**. The pair of downwardly inclined converging surface portions **207a**, **207b** converge along a draw direction **211** to form the root **145**. A draw plane **213** extends through the root **145** wherein the glass ribbon **103** may be drawn in the draw direction **211** along the draw plane **213**. As shown, the draw plane **213** can bisect the root **145** although the draw plane **213** may extend at other orientations relative to the root **145**.

[0050] In some embodiments, the molten material **121** can flow from the inlet **141** into the trough **201** of the forming vessel **143**. The molten material **121** can then overflow from the trough **201** by simultaneously flowing over corresponding weirs **203a**, **203b** and downward over the outer surfaces **205a**, **205b** of the corresponding weirs **203a**, **203b**. Respective streams of molten material **121** then flow along the downwardly inclined converging surface portions **207a**, **207b** of the forming wedge **209** to be drawn off the root **145** of the forming vessel **143**, where the flows converge and fuse into the glass ribbon **103**. The glass ribbon **103** may then be fusion drawn off the root **145** in the draw plane **213** along draw direction **211**.

[0051] In some embodiments, as shown in **FIG. 1**, the glass manufacturing apparatus **101** for fusion drawing the glass ribbon **103** can also include at least one edge roll assembly **149a, 149b**. As illustrated, each edge roll assembly **149a, 149b** can be identical with one another although different edge roll assembly configurations may be provided in further embodiments. As shown in **FIG. 2**, each edge roll assembly **149a, 149b** can include a pair of edge rolls **221** with a corresponding one of two opposed edge portions **301a, 301b** (see **FIG. 1**) of the glass ribbon **103** pinched between each pair of edge rolls **221**. As shown in **FIG. 1**, a first edge roll assembly **149a** (with a pair of edge rolls **221**) can be associated with a first edge portion **301a** of

the two opposed edge portions **301a, 301b**. As further shown in **FIG. 1**, a second edge roll assembly **149b** (with a pair of edge rolls **221**) can be associated with a second edge portion **301b** of the two opposed edge portions **301a, 301b.** In some embodiments, the edge rolls **221** can be configured to freely rotate although the edge rolls **221** may be driven rolls (e.g., driven by one or more motors), in further embodiments.

[0052] Outer edge beads **353, 355** of each of the opposed edge portions **301a, 301b** can be drawn through the corresponding pair of edge rolls **221** as the glass ribbon **103** is drawn off the root **145** of the forming wedge **209**. Each pair of edge rolls **221** can provide proper finishing of the corresponding outer edge beads **353, 355** of the opposed edge portions **301a, 301b** of the glass ribbon **103**. Indeed, edge roll finishing of the outer edge beads **353, 355** with the corresponding pairs of edge rolls **221** can provide desired edge characteristics and proper fusion of the opposed edge portions **301a, 301b** of the molten glass being pulled off opposed surfaces of respective edge directors **225** at each end of the forming wedge **209** (one edge director shown in **FIG. 2**). As shown in **FIGS. 1** and **2**, at least one or both of the edge rolls of the pairs of edge rolls **221** can include a knurled surface **227** that may finish one or both opposed surfaces of the outer edge beads **353**, **355** of the opposed edge portions **301a**, **301b** with a corresponding knurled surface **229** stamped into the glass surfaces of the outer edge beads **353**, **355** as the edge portions are finished with the pairs of edge rolls **221** of each edge roll assembly **149a**, **149b**.

[0053] As shown in **FIG. 1**, the opposed edge portions **301a, 301b** can be substantially identical to one another or the edge portions **301a, 301b** may have different configurations in further embodiments. As illustrated, a central portion **303** of the glass ribbon **103** can be defined between the two opposed edge portions **301a**, **301b**. **FIG. 14** illustrates representative features of the first edge portion **301a** with the understanding that the first edge portion **301a** may be identical to or similar to the second edge portion **301b**. In some embodiments, the outer edge bead **353**, **355** of the two opposed edge portions **301a**, **301b** can each include a thickness **363** (see **FIGS. 14** and **15**) that is greater than the thickness **"T"** of an interior portion **302** of the central portion **303** of the glass ribbon **103**. In some embodiments, the thickness **363**

can be greater than or equal to about 1 mm, for example, from about 1 mm to about 2 mm, for example, from about 1 mm to about 3 mm, although other thicknesses may be produced in further embodiments.

[0054] As further shown in **FIGS. 1** and **2**, the glass manufacturing apparatus **101** can further include a first and second pull roll assembly **151a**, **151b** associated with each respective edge portion **301a, 301b** to facilitate pulling of the glass ribbon **103** in the draw direction **211** of the draw plane **213**. As illustrated, each pull roll assembly **151a, 151b** can be identical with one another although different pull roll assembly configurations may be provided in further embodiments. As shown in **FIG. 2**, each pull roll assembly **151a**, **151b** can include a pair of pull rolls **153** with a corresponding outer edge bead **353**, **355** of the two opposed edge portions **301a, 301b** (see **FIG. 1**) of the glass ribbon **103** pinched between each pair of pull rolls **153**. As shown in **FIG. 1**, a first pull roll assembly **151a** (with a pair of pull rolls **153**) can be associated with the first edge portion **301a** of the two opposed edge portions **301a, 301b**. As further shown in **FIG. 1**, a second pull roll assembly **151b** (with a pair of pull rolls **153**) can be associated with the second edge portion **301b** of the two opposed edge portions **301a, 301b.** In some embodiments, the pull rolls **153** can be configured to be driven by one or more motors **155**.

[0055] Each outer edge bead **353, 355** of the opposed edge portions **301a**, **301b** can be drawn through the corresponding pair of pull rolls **153** as the glass ribbon **103** is drawn off the root **145** of the forming wedge **209**. The pull rolls **153** may be driven by the motors **155** to provide appropriate tension within the glass ribbon **103** and therefore facilitate drawing the glass ribbon **103** at an appropriate rate to provide desired attributes of the glass ribbon **103** (e.g., the thickness **"T"** of the interior portion **302** of the central portion **303** of the glass ribbon **103**). The knurled surface **229** of the outer edge beads **353, 355** of the two opposed edge portions **301a**, **301b** can increase the coefficient of friction and therefore provide appropriate gripping between the pull rolls **153** and the outer edge beads **353**, **355**. As such, slipping between the pull rolls **153** and the knurled surfaces **229** can be reduced or prevented to provide a precise and consistent pulling force to the glass ribbon **103**.

[0056] As shown in **FIG. 2** and **FIG. 4** which respectively illustrate a cross-sectional view of the glass manufacturing apparatus **101** along line **2-2** of **FIG. 1** and a cross-sectional view of the glass manufacturing apparatus **101** along line **4-4** of **FIG. 3**, the glass ribbon **103** may be drawn from the root **145** along the draw plane **213** in the draw direction **211** with a first major surface **215a** of the glass ribbon **103** and a second major surface **215b** of the glass ribbon **103** facing opposite directions and defining a thickness "**T**" of the interior portion **302** of the central portion **303** of the glass ribbon **103** that can be, for example, from about 40 micrometers (μm) to about 1 millimeter (mm), for example, from about 40 micrometers to about 0.5 millimeters, for example, from about 40 micrometers to about 500 micrometers, for example, from about 40 micrometers to about 300 micrometers, for example, from about 40 micrometers to about 200 micrometers, for example, from about 40 micrometers to about 100 micrometers, or, for example, about 40 micrometers, although other thicknesses may be provided in further embodiments. In addition, the glass ribbon **103** can include a variety of compositions including but not limited to glass, ceramic, glass-ceramic, soda-lime glass, borosilicate glass, alumino-borosilicate glass, an alkali-containing glass, an alkali-free glass, or any combination thereof.

[0057] In some embodiments, as shown in **FIG. 5**, the glass ribbon **103** can include a first cladding layer **501** on the first major surface **215a** of the glass ribbon **103** and a second cladding layer **502** on the second major surface **215b** of the glass ribbon **103**. A first major cladding surface **515a** of the first cladding layer **501** and a second major cladding surface **515b** of the second cladding layer **502** can face opposite directions and can define a total thickness "**t**" including the thickness "**T**" of the interior portion **302** of the central portion **303** of the glass ribbon **103** and the thickness of each of the first cladding layer **501** and the second cladding layer **502**. In some embodiments, the total thickness "**t**" can be for example, from about 100 micrometers (μm) to about 3 millimeters (mm), for example, from about 100 micrometers to about 2.5 millimeters, for example, from about 100 micrometers to about 2 millimeters, for example, from about 100 micrometers to about 1.5 millimeters, for example, from about 100 micrometers to about 1 millimeter, for example, from about 100 micrometers to about 0.5 millimeters, for example, from

about 100 micrometers to about 500 micrometers, for example, from about 100 micrometers to about 300 micrometers, for example, from about 100 micrometers to about 200 micrometers, or for example, about 100 micrometers, although other thicknesses may be provided in further embodiments.

[0058] In addition, the first cladding layer **501** and the second cladding layer **502** can include a variety of compositions including but not limited to glass, ceramic, glass-ceramic, soda-lime glass, borosilicate glass, alumino-borosilicate glass, an alkali-containing glass, an alkali-free glass, or any combination thereof. In some embodiments, the glass ribbon **103** can define a laminate glass including a core layer of glass disposed between the first cladding layer **501** and the second cladding layer **502**. The first cladding layer **501** and the second cladding layer **502** can, therefore be exterior layers (e.g., outermost layers). In some embodiments, the first cladding layer **501** can be fused to the first major surface **215a** of the glass ribbon **103** and the second cladding layer **502** can be fused to the second major surface **215b** of the glass ribbon **103**. In some embodiments, an interface between the first cladding layer **501** and the glass ribbon **103** and/or between the second cladding layer **502** and the glass ribbon **103** can be free of any bonding material (e.g., adhesive, a coating layer, or any other material to adhere the respective cladding layer **501**, **502** to the core layer of glass).

[0059] Accordingly, in some embodiments, the first cladding layer **501** and the second cladding layer **502** can be fused directly to the glass ribbon **103** and can be directly adjacent to the respective first major surface **215a** and second major surface **215b** of the glass ribbon **103**. In other embodiments, the glass ribbon **103** can include any suitable number of layers, such as two, four, or more layers, including one or more intermediate layers disposed between the core layer of the glass ribbon **103** and at least one of the first cladding layer **501** and the second cladding layer **502**. Thus, the first cladding layer **501** and the second cladding layer **502**, when provided, are intended to refer to the exterior (e.g., outermost) layers of the glass ribbon **103**, including the first major cladding surface **515a** of the first cladding layer **501** and the second major cladding surface **515b** of the second cladding layer **502**, regardless of the total number of layers included in the glass ribbon **103**.

[0060] In some embodiments, the core layer (e.g., glass ribbon **103**) can include a core coefficient of thermal expansion, and the cladding layer (e.g., the first cladding layer **501**, the second cladding layer **502**) can include a cladding coefficient of thermal expansion. As used herein, the term "coefficient of thermal expansion," or "CTE," refers to the average coefficient of linear thermal expansion of a given material or layer between 0 °C and 300 °C, unless otherwise indicated. For example, the core layer can be formed from a material having a composition including the core CTE and the cladding layer **501**, **502** can be formed from another material having a composition including the cladding CTE. In some embodiments, the core CTE can be greater than the cladding CTE such that the core layer is in tension and the cladding layer **501**, **502** is in compression, thereby strengthening the glass laminate article. The difference in CTE between the core layer and the cladding layer **501**, **502** can be referred to as CTE mismatch. In some embodiments, the CTE of the core layer and the CTE of the cladding layer **501**, **502** can differ by at least about $5x10^{-7}°C^{-1}$, at least about $15x10^{-7}°C^{-1}$, at least about $25x10^{-7}°C^{-1}$, or at least about $30x10^{-7}°C^{-1}$. In some embodiments, the CTE of the core layer and the CTE of the cladding layer **501**, **502** can differ by from about $5x10^{-7}°C^{-1}$ to about $30x10^{-7}°C^{-1}$. In another embodiment, the CTE of the core layer and the CTE of the cladding layer **501**, **502** can differ by from about $15x10^{-7}°C^{-1}$ to about $30x10^{-7}°C^{-1}$. In another embodiment, the CTE of the core layer and the CTE of the cladding layer **501**, **502** can differ by from about $25x10^{-7}°C^{-1}$ to about $30x10^{-7}°C^{-1}$ although other ranges may be provided in further embodiments.

[0061] In some embodiments, based at least in part on the CTE mismatch between the core layer and the cladding layer **501**, **502**, the laminated glass can provide a glass article that, compared to for example a non-laminated glass article, has improved resistance to breakage and therefore improved mechanical reliability. Additionally, in some embodiments, based at least in part on the CTE mismatch between the core layer and the cladding layer **501**, **502**, the laminated glass may be more likely to crack and break when cut as compared to cutting non-laminated glass. Furthermore, while not being bound by any particular theory, it is believed that selection of the glass composition of the clad and core can improve encapsulation of the edge bead with one of the first cladding layer 501 and the second cladding layer

502 by the surface tension of the clad glass being lower than the surface tension of the core glass. Consequently, proper selection of glass compositions with the differing CTE discussed above can result in enhanced encapsulation of the edge bead by the cladding layer(s), thereby strengthening the edge bead while also strengthening the glass laminate article with the cladding layers in compression and the core layer in tension. Advantageously, the methods and apparatus disclosed herein can be employed to cut either or both a laminated glass article and a non-laminated glass article.

[0062] Methods and apparatus for separating at least one of the first edge portion **301a** and the second edge portion **301b** from the central portion **303** of the glass ribbon **103** will now be described. In some embodiments, a method of manufacturing glass can include forming the glass ribbon **103** from a quantity of molten material **121**, drawing the glass ribbon **103** in a draw direction **211**, where the glass ribbon **103** includes a pair of opposed edge portions (e.g., first edge portion **301a**, second edge portion **301b**) and a central portion **303** laterally spanning between the opposed edge portions **301a, 301b**. The method can include separating the first edge portion **301a** of the pair of opposed edge portions **301a, 301b** from the central portion **303** by cutting through the glass ribbon **103** while the glass ribbon **103** is being drawn in the draw direction **211**. Similarly, in some embodiments, the method can further include separating the second edge portion **301b** of the pair of opposed edge portions **301a, 301b** from the central portion **303** by cutting through the glass ribbon **103** while the glass ribbon **103** is being drawn in the draw direction **211**.

[0063] As illustrated in **FIGS. 1-3**, in some embodiments, the glass manufacturing apparatus **101** can include a first cutting torch **170** oriented to cut through the glass ribbon **103** to separate the first edge portion **301a** of the glass ribbon **103** from the central portion **303** of the glass ribbon **103** while the glass ribbon **103** is drawn from the glass former **140**. In some embodiments, the glass manufacturing apparatus **101** can further include a second cutting torch **171** oriented to cut through the glass ribbon **103** to separate the second edge portion **301b** from the central portion **303** of the glass ribbon **103** while the glass ribbon **103** is drawn from the glass former **140**. It is to be understood that while some embodiments of a method for

manufacturing glass and a glass manufacturing apparatus **101** disclosed herein can include a cutting torch **170** (as illustrated), other embodiments may include other cutting devices without departing from the scope of disclosure. Therefore, unless otherwise noted, the present disclosure is to be understood to encompass other cutting devices oriented to cut through the glass ribbon **103** to create a gap **325**, including but not limited to mechanical scoring tools, knives, shears, lasers, etc.

[0064] In some embodiments, as discussed above, each of the opposed edge portions (e.g., first edge portion **301a**, second edge portion **301b**) of the glass ribbon **103** can include the outer edge bead (e.g., the first outer edge bead **353** and the second outer edge bead **355**). The thickness **363** of the outer edge beads **353**, **355** can be greater than the thickness "**T**" of the interior portion **302** of the central portion **303** of the glass ribbon **103**. In some embodiments, the outer edge beads **353**, **355** can be desirable by aiding in sheet stabilization, sheet width loss control, thickness control, etc. during the manufacturing process where the glass ribbon **103** can be formed and stretched by viscous deformation. However, in some embodiments, the outer edge beads **353**, **355** can, among other features, impart undesirable stresses on the glass ribbon **103**, can distort a shape of the glass ribbon **103**, can impart undesirable features including wrinkles in the glass ribbon **103**. In further embodiments, the outer edge beads **353, 355** can make it difficult to separate, for example, a glass sheet **104** (see **FIG. 3**) from the glass ribbon **103**. For example, as the glass ribbon **103** cools from a higher temperature (e.g., of the molten material **121**) to a lower temperature (e.g., of the glass ribbon **103**) as the glass ribbon **103** transition from a viscous state, to a viscous-elastic state, and then to an elastic state throughout the glass manufacturing process, internal stresses in the glass ribbon **103** can occur based at least in part on temperature gradients resulting in different cooling rates between regions of the glass ribbon **103** having different thicknesses. In some embodiments, thickness differences between the outer edge beads **353**, **355** and the central portion **303** of the glass ribbon **103**, for example, can induce large temperature and stress gradients in the glass ribbon **103**.

[0065] Removing the first edge portion **301a** of the glass ribbon **103** including the first outer edge bead **353** and the second edge portion **301b** of the glass ribbon **103**

including the second outer edge bead **355** can, therefore, reduce the occurrence of such large temperature and stress gradients in the glass ribbon **103** and thus, in some embodiments, improve the overall strength and quality of the glass ribbon **103**. Moreover, removing the first edge portion **301a** of the glass ribbon **103** including the first outer edge bead **353** and the second edge portion **301b** of the glass ribbon **103** including the second outer edge bead **355** can reduce the likelihood of cracks that may be present in the outer edge beads **353**, **355** from propagating, for example, into the central portion **303** of the glass ribbon **103** that can cause the glass ribbon **103** to crack, fracture, and fail.

[0066] In some embodiments, cutting through the glass ribbon **103** (e.g., with the first cutting torch **170**) can create a first gap **325** between a first central cut edge **305** of the central portion **303** and a first cut edge **306** of the first edge portion **301a**. Similarly, cutting through the glass ribbon **103** (e.g., with the second cutting torch **171**) can create a second gap **326** between a second central cut edge **307** of the central portion **303** and a second cut edge **308** of the second edge portion **301b**. Advantageously, the first gap **325** and the second gap **326** can provide a spaced separation between the first central cut edge **305** of the central portion **303** and the first cut edge **306** of the first edge portion **301a** as well as between the second central cut edge **307** of the central portion **303** and the second cut edge **308** of the second edge portion **301b**. The spaced separation can prevent contact and interference between features of the first edge portion **301a** of the glass ribbon **103**, the second edge portion **301b** of the glass ribbon **103**, and the central portion **303** of the glass ribbon **103** that may otherwise, cause chipping, cracking, and damage to the glass ribbon **103**.

[0067] In some embodiments, the gap (e.g., the first gap **325**, the second gap **326**) can be created at any elevation relative to the draw direction **211** along the glass ribbon **103** (e.g., at any elevation on the glass ribbon **103** below the glass former **140**). In some embodiments, the gap **325**, **326** can be created in the glass ribbon **103** when the glass ribbon **103** is in a viscous state prior to the glass ribbon **103** transitioning to an elastic state. In some embodiments, the gap **325**, **326** can be created in the glass ribbon **103** when the glass ribbon **103** is in an elastic state after having transitioned

from a viscous state. In some embodiments, the gap **325**, **326** can be created in the glass ribbon **103** when the glass ribbon **103** is in a viscous-elastic state while transitioning from a viscous state to an elastic state. In some embodiments, the gap **325**, **326** can be created in the glass ribbon **103** when the glass ribbon **103** is, for example, reheated to be in a viscous state (e.g., locally reheated in the region to be cut) after having already transitioned from a viscous state to an elastic state. In some embodiments, a higher elevation of the cut relative to the draw direction **211** (e.g., closer to the glass former **140**) can correspond to a higher relative temperature of the glass ribbon **103**. For example, the glass ribbon **103** can cool from a higher temperature to a lower temperature as it is drawn from the glass former **140** in the draw direction **211**. Cutting the glass ribbon **103** when the glass ribbon **103** is at a higher temperature (e.g., cutting the glass ribbon **103** at a location having a higher elevation relative to the draw direction **211**) can reduce the tension stress in the cut edges (e.g., the first central cut edge **305** of the central portion **303**, the first cut edge **306** of the first edge portion **301a**) which can improve the quality and strength of the cut edges as compared to cut edges that are created when the glass ribbon **103** is at a relatively lower temperature. In some embodiments, creating the gap **325**, **326** when the glass ribbon **103** is in a viscous state or when the glass ribbon **103** is transitioning from a viscous state to an elastic state can strengthen the cut edges and therefore reduce the likelihood of secondary cracking of the cut edges after they are formed. Accordingly, in some embodiments, the methods and apparatus disclosed herein can provide a stable cutting process that can be employed to continuously separate the edge portions **301a**, **301b** of the glass ribbon **103** from the central portion **303** of the glass ribbon **103**.

[0068] In some embodiments, cutting through the glass ribbon **103** (e.g., with the first cutting torch **170**) can provide the first central cut edge **305** of the central portion **303** with a first central cut edge bead **309** and can provide the first cut edge **306** of the first edge portion **301a** with a first cut edge bead **310**. Similarly, in some embodiments, cutting through the glass ribbon **103** (e.g., with the second cutting torch **171**) can provide the second central cut edge **307** of the central portion **303** with a second central cut edge bead **311** and can provide the second cut edge **308** of the

second edge portion **301b** with a second cut edge bead **312**. Accordingly, in some embodiments, the flame-polished edges of the first central cut edge **305** of the central portion **303** and the first cut edge **306** of the first edge portion **301a** as well as the second central cut edge **307** of the central portion **303** and the second cut edge **308** of the second edge portion **301b** can provide, respectively, a flame-polished first cut edge bead **310**, a flame-polished first central cut edge bead **309**, a flame-polished second cut edge bead **312**, and a flame-polished second central cut edge bead **311**.

[0069] In addition, the first cutting torch **170** and the second cutting torch **171** can simultaneously cut through the glass ribbon **103** and finish (e.g., flame-polish) the first central cut edge **305** of the central portion **303** and the first cut edge **306** of the first edge portion **301a** as well as the second central cut edge **307** of the central portion **303** and the second cut edge **308** of the second edge portion **301b**. In some embodiments, as compared to, for example, edges that are separated by scoring, cracking, etc., a flame-polished edge that is separated by cutting through the glass ribbon **103** with a cutting torch **170**, **171** can include relatively less defects, flaws, and cracks which can reduce the likelihood of crack initiation, crack formation, and crack propagation in the glass ribbon **103**. Likewise, in some embodiments, a flame-polished edge including a flame-polished edge bead that is separated by cutting through the glass ribbon **103** with a cutting torch **170**, **171** can include relatively less defects, flaws, and cracks which can reduce the likelihood of crack initiation, crack formation, and crack propagation in the glass ribbon **103**.

[0070] Additionally, in some embodiments, the first central cut edge **305** of the central portion **303** and the first cut edge **306** of the first edge portion **301a** as well as the second central cut edge **307** of the central portion **303** and the second cut edge **308** of the second edge portion **301b** can also be tempered as the edges cool during the glass manufacturing process which can provide edges having less stress than may be observed in edges that are flame-polished without tempering. Accordingly, in some embodiments, a continuous, online process for removing the first edge portion **301a** including the first outer edge bead **353** and the second edge portion **301b** including the second outer edge bead **355** from the glass ribbon **103** can be provided. Such removal can provide a central portion **303** with the interior portion **302** disposed

between polished central cut edge beads **309, 311** that can reduce stress concentrations while still providing central cut edge beads **309, 311** that can provide durable edges to avoid damage during subsequent processing and/or handling techniques. Indeed, compared to the outer edge beads **353, 355**, the polished central cut edge beads **309, 311** do not include the stress concentrations associated with formation of the outer edge beads **353, 355**. Furthermore, compared to edges without edge beads (e.g., by way of full body crack propagation), the polished central cut edge beads **309, 311** can provide a more durable edge configuration that may resist cracks, chips or other edge imperfections that may result from the relatively fragile full body cut edges that do not include an edge bead. As such, the polished central cut edge beads **309, 311** may reduce crack failures through the central portion **303** during handling and/or processing techniques.

[0071] In some embodiments, (e.g., as shown in **FIG. 3** with respect to the second edge portion **301b)** a guide roller **335** can be provided to guide the separated second edge portion **301b**. Although not shown, a similar guide roller may be provided to guide the separated first edge portion **301a**. The guide roller **335** can direct the second edge portion **301b** and/or the first edge portion **301a** into, for example, a container (e.g., cullet chute) where the corresponding separated edge portion **301a**, **301b** can then be discarded. In some embodiments, a heater **336** and a cooler **337** can be provided to, respectively, heat and then cool the separated edge portion **301a**, **301b** to fracture, crack, and break (e.g., crizzle) the separated edge portion **301a**, **301b**. In some embodiments, the heater **336** can include any one or more of an electric heater, a gas heater, and any other suitable heater. In some embodiments, the heater **336** can include the same or similar features as the cutting torch **170**, including a flame oriented to impinge on the separated edge portion **301a**, **301b** to heat the separated edge portion **301a**, **301b**. In some embodiments, the cooler **337** can include a fluid cooler oriented to provide a cooled fluid (e.g., gas, liquid) that impinges on the heated separated edge portion **301a**, **301b**. The successive heating by the heater **336** and relatively rapid cooling by the cooler **337** can induce thermal stresses that can cause the glass to fracture, crack, and break (e.g., crizzle, as shown with respect to the second separated edge portion **301b** shown in

FIG. 3). In some embodiments, where the edge portion **301a**, **301b** is at a temperature high enough for thermal induced stresses to occur when the edge portion **301a**, **301b** is shocked with a cooler temperature, the cooler **337** may be provided without the heater **336** to relatively rapidly cool the edge portion **301a**, **301b** and thereafter induce thermal stresses that can cause the glass to fracture, crack, and break (e.g., crizzle). The crizzled edge portion (including any pieces of glass broken from the edge portion) can then be deposited into the container for subsequent disposal.

[0072] In some embodiments, the guide roller **335** can offset the separated edge portion **301a**, **301b** relative to the central portion **303** to further separate the first central cut edge **305** of the central portion **303** relative to the first cut edge **306** of the first edge portion **301a** and the second central cut edge **307** of the central portion **303** relative to the second cut edge **308** of the second edge portion **301b**. For example, an offset of the central portion **303** of the glass ribbon **103** relative to the separated first edge portion **301a** and the separated second edge portion **301b** can be provided. For example, the central portion **303**, the first separated edge portion **301a**, and the second separated edge portion **301b** can be offset with respect to the draw plane **213** relative to each other. In such an orientation, the first cut edge bead **310** can be further separated from the first central cut edge bead **309** and the second cut edge bead **312** can be further separated from the second central cut edge bead **311**. It is to be understood that the guide roller **335**, the heater **336**, and the cooler **337**, can be applied to one or both of the first separated edge portion **301a** and/or the second separated edge portion **301b** without departing from the scope of the disclosure.

[0073] As further illustrated in **FIG. 3**, in some embodiments, the method can further include separating a glass sheet **104** from the central portion **303** of the glass ribbon **103** along a separation path **322** that is transverse to the draw direction **211** of the glass ribbon **103**. For example, a glass separator **350** (e.g., a travel anvil machine) can be employed to separate a glass sheet **104** from the central portion **303** of the glass ribbon **103** along the separation path **322**. In some embodiments, the glass separator **350** can include a mechanical scoring tool to provide a score path on the glass ribbon **103** along the separation path **322** and a robot (not shown) to bend the glass ribbon **103** about the score path to separate the glass sheet **104** from the glass

ribbon **103** along the separation path **322**. It is to be understood that any suitable glass separator **350** including mechanical separation, laser separation, etc. can be provided in other embodiments without departing from the scope of the disclosure.

[0074] In some embodiments, the method can further include removing at least one of the first central cut edge bead **309** and the second central cut edge bead **311** from the central portion **303** to provide a trimmed central portion (e.g., trimmed glass sheet **304**). In some embodiments (not shown), prior to separating the glass sheet **104** from the central portion **303** of the glass ribbon **103** the at least one of the first central cut edge bead **309** and the second central cut edge bead **311** can be removed from the central portion **303** to provide a trimmed central portion. In some embodiments, the glass sheet **104** can include at least one of the first central cut edge bead **309** and the second central cut edge bead **311** and the method can further include removing at least one of the at least one of the first central cut edge bead **309** and the second central cut edge bead **311** from the glass sheet **104** (e.g., as shown by separation paths **329**, **331**) to provide the trimmed glass sheet **304**. The trimmed glass sheet **304** can then be employed in a variety of display applications, for example. Various techniques may be used to separate the central cut edge beads **309, 311** along the separation paths **329, 331**. In one embodiment, a full body crack may be propagated by a laser. In further embodiments, a full body crack may be propagated by a laser followed by quenching with a cooling fluid. In such embodiments, the newly formed edges of the trimmed central portion may be provided with mirror edge surfaces that are substantially or entirely free of edge defects. In some embodiments, the central cut edge beads **309, 311** can be cut away after handling and/or processing that may have otherwise damaged the mirror edge surfaces. As such, the central cut edge beads **309, 311** can provide enhanced processing and/or handling of the glass ribbon **103** and/or glass sheet **104** prior to being removed, at an appropriate time, to provide the final product without the central cut edge beads **309, 311**.

[0075] In some embodiments, a plurality of glass sheets **104**, each including the first central cut edge bead **309** and the second central cut edge bead **311**, can be stacked together to provide a stack of glass sheets **340** that can, for example, be stored, transported, etc. In some embodiments, the stack of glass sheets **340** can be oriented

at any angle (e.g., horizontally, vertically, diagonally, etc.) relative to the force of gravity to permit various types of storage and transportation of the stack of glass sheets **340**. Advantageously, the glass sheet **104** including the first central cut edge bead **309** and the second central cut edge bead **311** can be stacked with the first central cut edge bead **309** and the second central cut edge bead **311** providing a space **345** between central portions **303** of adjacent glass sheets **104** in the stack of glass sheets **340**. In some embodiments, the first central cut edge bead **309** and the second central cut edge bead **311** of adjacent glass sheets **104** can be in contact with each other to provide the space **345** between central portions **303** of adjacent glass sheets **104** in the stack of glass sheets **340**. In some embodiments, an intermediate spaced (e.g., interleaf paper) can be provided between the first central cut edge bead **309** and the second central cut edge bead **311** of adjacent glass sheets **104** to prevent, for example, glass-on-glass contact between the first central cut edge bead **309** and the second central cut edge bead **311** of adjacent glass sheets **104**. Moreover, glass-on-glass contact between the pristine major surfaces **215a**, **215b** of the glass ribbon **103** can be avoided by spacing the central portions **303** of adjacent glass sheets **104** apart, and scratches, chips, and damage caused from glass-on-glass contact of the pristine major surfaces **215a**, **215b** of the glass ribbon **103** can likewise be avoided or reduced. In some embodiments, one or more of the glass sheets **104** from the stack of glass sheets **340** can be further processed by, for example, removing at least one of the at least one of the first central cut edge bead **309** and the second central cut edge bead **311** from the glass sheet **104** (e.g., as shown by separation paths **329**, **331**) to provide the trimmed glass sheet **304** which can then be employed in a variety of display applications.

[0076] FIGS. 6-9 schematically illustrate some embodiments of a cross-sectional view of the glass manufacturing apparatus **101** along line **6-6** of **FIG. 3** in accordance with the embodiment of **FIG. 4**. Likewise, **FIGS. 10-13** schematically illustrate some embodiments of a cross-sectional view of the glass manufacturing apparatus **101** along line **6-6** of **FIG. 3** in accordance with the embodiment of **FIG. 5**. Although methods and apparatus may be illustrated herein with respect to separating the first edge portion **301a** of the pair of opposed edge portions **301a, 301b** from the

central portion **303** (e.g., with the first cutting torch **170**), it is to be understood that, in further embodiments, the same or similar features can be applied to separate the second edge portion **301b** of the pair of opposed edge portions **301a, 301b** from the central portion **303** (e.g., with the second cutting torch **171**).

[0077] As shown in **FIG. 6**, in some embodiments, the cutting torch **170** can be oriented to direct a flame **270** from the cutting torch **170** to contact the glass ribbon **103** being drawn from the glass former **140**. In some embodiments the cutting torch **170** can be oriented to direct the flame **270** to contact either the first major surface **215a** of the glass ribbon **103** or the second major surface **215b** of the glass ribbon **103**. In some embodiments, a cutting torch **170** can be provided on each side of the glass ribbon **103** to contact both the first major surface **215a** of the glass ribbon **103** and the second major surface **215b** of the glass ribbon **103**. Similarly, as shown in **FIG. 10**, in some embodiments, the cutting torch **170** can be oriented to direct a flame **270** from the cutting torch **170** to contact the first cladding layer **501** as the glass ribbon **103** being drawn from the glass former **140**. In some embodiments the cutting torch **170** can be oriented to direct the flame **270** to contact either the first major cladding surface **515a** of the first cladding layer **501** or the second major cladding surface **515b** of the second cladding layer **502**. In some embodiments, a cutting torch **170** can be provided on each side of the glass ribbon **103** to contact both the first major cladding surface **515a** of the first cladding layer **501** and the second major cladding surface **515b** of the second cladding layer **502**.

[0078] In some embodiments, the cutting torch **170** can include a pressurized fluid that can be ignited to produce the flame **270**. Accordingly, unlike some other sources of heat (e.g., a laser) than can produce heat in the form of non-contact thermal radiation, the cutting torch **170** of the present disclosure can produce a flame **270** that can provide heat as a pressurized jet that can impinge on a surface, applying both a force from the pressure of the jet in addition to thermal heat from the ignition (e.g., combustion, burning) of the pressurized fluid. For example, as shown in **FIG. 7**, the cutting torch **170** can create a bulge **175** in the glass ribbon **103** based at least in part on the impinging pressure of the flame **270** from the cutting torch **170** on the glass ribbon **103**. Similarly, as shown in **FIG. 11**, the cutting torch **170** can create the bulge

175 in the glass ribbon **103** and a corresponding first cladding bulge **176** in the first cladding layer **501** and a second cladding bulge **177** in the second cladding layer **502** based at least in part on the impinging pressure of the flame **270** from the cutting torch **170** on the glass ribbon **103** including the first cladding layer **501** and the second cladding layer **502**.

[0079] Without intending to be limited by theory, it is believed that contacting the glass ribbon **103** with the flame **270** from the cutting torch **170** to provide a bulge **175** in the glass ribbon **103** can aid in the cutting of the glass ribbon **103** by, in addition to heating the glass ribbon **103**, also stretching and pulling a localized heated region of the glass ribbon **103** until the glass ribbon **103** separates. For example, as shown in **FIG. 8**, the cutting torch **170** can melt the glass ribbon **103** and the bulge **175** can begin to thin creating a first edge bead formation **310a** and a first central edge bead formation **309a**. Similarly, as shown in **FIG. 12**, the cutting torch **170** can melt the glass ribbon **103** including the first cladding layer **501** and the second cladding layer **502** and the bulge **175** including the corresponding first cladding bulge **176** and second cladding bulge **177** can begin to thin creating the first edge bead formation **310a** and the first central edge bead formation **309a**.

[0080] As shown in **FIG. 9**, the cutting torch **170** can cut completely through the glass ribbon **103** separating the first edge portion **301a** from the central portion **303**. Upon separation, at least a remaining portion of melted glass from the bulge **175** can combine with the first edge bead formation **310a** to form the first cut edge bead **310** and at least another remaining portion of melted glass from the bulge **175** can combine with the first central edge bead formation **309a** to form the first central cut edge bead **309**. Similarly, as shown in **FIG. 13**, the cutting torch **170** can cut completely through the glass ribbon **103** including the first cladding layer **501** and the second cladding layer **502** separating the first edge portion **301a** from the central portion **303**. Upon separation, at least a remaining portion of melted glass from the bulge **175** can combine with the first edge bead formation **310a** to form the first cut edge bead **310** that can be encapsulated with at least one of the melted first cladding layer **501** and second cladding layer **502** from, for example, the corresponding first cladding bulge **176** and second cladding bulge **177**. Likewise, at least another

remaining portion of melted glass from the bulge **175** can combine with the first central edge bead formation **309a** to form the first central cut edge bead **309** that can be encapsulated with at least one of the melted first cladding layer **501** and second cladding layer **502** from, for example, the corresponding first cladding bulge **176** and second cladding bulge **177**.

[0081] Accordingly, the cutting torch **170** of the present disclosure can provide advantageous benefits not achievable with some other sources of heat alone, including but not limited to a laser used alone as the only heating source. Moreover, the cutting torch **170** of the present disclosure can be employed without significant modification of the glass manufacturing apparatus **101** to cut through the glass ribbon **103** relatively less expensively than, for example, conventional laser cutting techniques which, in some embodiments, can include complex mirrors that may require intricate alignment, setup, and maintenance. It is to be understood that the exemplary cutting torch **170** described herein can include any one or more cutting torches, including a combination of any one or more of a blowtorch, a plasma torch, a line burner, a pencil burner, a piloted fine tip burner, a gas torch, an oxygen-gas torch (e.g., an oxygen-acetylene torch), and any other suitable cutting torches. Moreover, it is to be understood that various features of the cutting torch **170** including but not limited to, the type of tip or tips of the cutting torch **170**, the flame **270** setting of the cutting torch **170**, a distance of the cutting torch **170** from the glass ribbon **103**, etc. can be modified to provide a cutting torch **170** that can cut (e.g., melt) through the glass ribbon **103** without departing from the scope of disclosure.

[0082] In some embodiments, the cutting torch **170** can include a flame **270** provided, for example, from a single orifice of the cutting torch **170** to cut through the glass ribbon **103**. In other embodiments, the cutting torch **170** can include a plurality of orifices producing a corresponding plurality of flames to cut through the glass ribbon **103**. In some embodiments, the cutting torch **170** can include a plurality of cutting torches including a plurality of flames to cut through the glass ribbon **103**. For example, in some embodiments, one flame can be provided to soften the glass ribbon **103** and another flame can be provided to cut through the softened glass ribbon **103**. The one flame and the other flame can be provided from the same cutting torch (e.g.,

from a first orifice and a second orifice of cutting torch **170**). In addition or alternatively, the one flame and the other flame can be provided from different cutting torches, each of which can include the same or similar features as cutting torch **170**, that can be positioned in a spaced relationship from each other (e.g., downstream along the draw direction **211**) to respectively soften the glass ribbon **103** (e.g., with one cutting torch) and then cut through the softened glass ribbon **103** (e.g., with another cutting torch) as the glass ribbon **103** is being drawn in the draw direction **211**. In some embodiments, the cutting torch **170** can include any number of flames that either individually or together cut through the glass ribbon **103** as the glass ribbon **103** is drawn in the draw direction **211**. Additionally, in some embodiments, the cutting torch **170** can be oriented to remain stationary relative to the glass ribbon **103** as the glass ribbon **103** is drawn in the draw direction **211**. In some embodiments, the cutting torch **170** can be oriented to move relative to the glass ribbon **103**. For example, in some embodiments, the cutting torch **170** can be oriented to traverse in the draw direction **211** at a same speed or a different speed than a speed at which the glass ribbon **103** is drawn to, for example, follow a location on the glass ribbon **103** to cut through the glass ribbon **103** at that location.

[0083] As shown in **FIG. 14** which illustrates an embodiment of a cross-sectional view of the glass manufacturing apparatus **101** along line **14-14** of **FIG. 3**, in some embodiments, the first central cut edge bead **309** can include a first central cut edge bead thickness **319** that is greater than the thickness "**T**" of the interior portion **302** of the central portion **303** of the glass ribbon **103**. In some embodiments, the first outer edge bead **353** can include a first outer edge bead thickness **363** that is greater than the thickness "**T**" of the interior portion **302** of the central portion **303** of the glass ribbon **103**. In some embodiments, the first central cut edge bead thickness **319** of the first central cut edge bead **309** of the central portion **303** can be greater than the first outer edge bead thickness **363** of the first outer edge bead **353** of the first edge portion **301a** and also greater than the thickness "**T**" of the interior portion **302** of the central portion **303** of the glass ribbon **103**.

[0084] Similarly, as shown in **FIG. 15**, in some embodiments, the first central cut edge bead **309** can include the first central cut edge bead thickness **319** that is

greater than the thickness "**T**" of the interior portion **302** of the central portion **303** of the glass ribbon **103**. Furthermore, a first central cut cladding edge bead thickness **320** can be greater than the total thickness "**t**" of the interior portion **302** of the central portion **303** of the glass ribbon **103** including the first cladding layer **501** and the second cladding layer **502**. In some embodiments, the first outer edge bead **353** can include a first outer edge bead thickness **363** that is greater than the thickness "**T**" of the interior portion **302** of the central portion **303** of the glass ribbon **103**. Likewise, in some embodiments, the first central cut cladding edge bead thickness **320** of the first central cut edge bead **309** including the first cladding layer **501** and the second cladding layer **502** can be greater than the first outer edge bead thickness **363** of the first outer edge bead **353** of the first edge portion **301a** and also greater than the total thickness "**t**" of the interior portion **302** of the central portion **303** of the glass ribbon **103** including the first cladding layer **501** and the second cladding layer **502**.

[0085] As shown, in **FIG. 14**, in some embodiments, the gap **325** can include a distance "**G**" of, for example, from about 1 mm to about 20 mm, for example, from about 1 mm to about 5 mm, for example, from about 5 mm to about 10 mm, for example, from about 10 mm to about 15 mm, for example, from about 15 mm to about 20 mm, for example, from about 1 mm to about 15 mm, for example, from about 1 mm to about 10 mm, although other distances can be provided in further embodiments. In some embodiments, the distance "**G**" can be defined between the first central cut edge **305** including the first central cut edge bead **309** of the central portion **303** and the first cut edge **306** including the first cut edge bead **310** of the first edge portion **301a**. Similarly, as shown in **FIG. 15**, in some embodiments cutting through the glass ribbon **103**, the first cladding layer **501**, and the second cladding layer **502** can create the gap **325** that can include a distance "**g**" of, for example, from about 1 mm to about 20 mm, for example, from about 1 mm to about 5 mm, for example, from about 5 mm to about 10 mm, for example, from about 10 mm to about 15 mm, for example, from about 15 mm to about 20 mm, for example, from about 1 mm to about 15 mm, for example, from about 1 mm to about 10 mm, although other distances can be provided in further embodiments. In some embodiments, the gap **325** can include the distance "**G**" defined between the first central cut edge **305**

including the first central cut edge bead **309** of the central portion **303** and the first cut edge **306** including the first cut edge bead **310** of the first edge portion **301a** as well as the distance "**g**" between the at least one of the first cladding layer **501** and the second cladding layer **502** that can encapsulate the first central cut edge **305** including the first central cut edge bead **309** of the central portion **303** and the first cut edge **306** including the first cut edge bead **310** of the first edge portion **301a**. Although illustrated in **FIG. 15**, as encapsulating the first cut edge bead **310** of the first edge portion **301a**, in some embodiments, the at least one of the first cladding layer **501** and the second cladding layer **502** may not encapsulate the first cut edge bead **310** of the first edge portion **301a**. Because the first edge portion **301a** can be separated from the central portion **303** of the glass ribbon **103** and subsequently disposed of, in some embodiments, the quality and characteristics of the first cut edge **306** of the first edge portion **301a** may be of less concern.

[0086] Accordingly, in some embodiments, as compared to conventional techniques (e.g., propagating a crack) to separate the first edge portion **301a** of the glass ribbon **103** from the central portion **303** of the glass ribbon **103** which attempt to create a separation between the first edge portion **301a** and the central portion **303** that does not alter the thickness "**T**" of the interior portion **302** of the central portion **303** of the glass ribbon **103** at the first central cut edge **305**, the features of the present disclosure can create a first central cut edge bead **309** at the first central cut edge **305** of the central portion **303** that includes a first central cut edge bead thickness **319** that is greater than the thickness "**T**" of the interior portion **302** of the central portion **303** of the glass ribbon **103**. Moreover, the first central cut edge **305** including the first central cut edge bead **309** can, in some embodiments, provide various advantages over the cut edges of the prior art including but not limited to relatively smooth cut edges that are relatively free of cracks, chips, and defects that may otherwise be present in edges cut with conventional techniques. In addition, when encapsulated by at least one of the first cladding layer **501** and the second cladding layer **502**, the first central cut edge **305** including the first central cut edge bead **309** can further strengthen and protect the first central cut edge **305** of the central portion **303** of the glass ribbon **103** and reduce the likelihood of cracks, chips, and defects in the glass ribbon **103**.

[0087] In some embodiments, the first central cut edge bead thickness **319** can be based at least in part on the distance "**G**" of the gap **325** and the thickness "**T**" of the glass ribbon **103**. For example, based at least in part on conservation of mass of the material that is separated to form the gap **325**, a larger gap **325** (e.g., distance "**G**") and/or a greater thickness "**T**" can produce a central cut edge bead **309** with a correspondingly larger thickness **319** that is greater than the thickness "**T**" of the interior portion **302** of the central portion **303** of the glass ribbon **103**. Likewise, based at least in part on conservation of mass of the material that is separated to form the gap **325**, a smaller gap **325** (e.g., distance "**G**") and/or a smaller thickness "**T**" can produce a central cut edge bead **309** with a correspondingly smaller thickness **319** that is greater than the thickness "**T**" of the interior portion **302** of the central portion **303** of the glass ribbon **103**, but to a lesser degree than the thickness **319** of the central cut edge bead **309** created from a proportionally larger gap **325** (e.g., distance "**G**") and/or a proportionally greater thickness "**T**".

[0088] Similarly, in some embodiments, the first central cut cladding edge bead thickness **320** can be based at least in part on the distance "**g**" of the gap **325** and the total thickness "**t**" of the glass ribbon **103** and the first and second cladding layers **501**, **502**. For example, based at least in part on conservation of mass of the material that is separated to form the gap **325**, a larger gap **325** (e.g., distance "**g**") and/or a greater total thickness "**t**" can produce an encapsulated central cut edge bead **309** with a correspondingly larger thickness **320** that is greater than the total thickness "**t**" of the interior portion **302** of the central portion **303** of the glass ribbon **103**. Likewise, based at least in part on conservation of mass of the material that is separated to form the gap **325**, a smaller gap **325** (e.g., distance "**g**") and/or a smaller total thickness "**t**" can produce an encapsulated central cut edge bead **309** with a correspondingly smaller thickness **320** that is greater than the thickness "**T**" of the interior portion **302** of the central portion **303** of the glass ribbon **103**, but to a lesser degree than the thickness **320** of the encapsulated central cut edge bead **309** created from a proportionally larger gap **325** (e.g., distance "**g**") and/or a proportionally greater total thickness "**t**".

[0089] Accordingly, the smooth, defect-free cut edges of the present disclosure can, in some embodiments, increase stability of the glass manufacturing

process, increase strength of and reduce stress in the glass ribbon **103**, and can provide a central portion **303** of the glass ribbon **103** from which glass sheets **104** can be separated without interference from the first edge portion **301a** and the second edge portion **301b** of the glass ribbon **103**. For example, the first edge portion **301a** and the second edge portion **301b** can include the first outer edge bead **353** and the second outer edge bead **355** as well as a first cladding bead **503** and a second cladding bead **504**. The first cladding bead **503** and the second cladding bead **504** can be present, in some embodiments, when the first cladding layer **501** and the second cladding layer **502** are provided on the glass ribbon **103**. The first outer edge bead **353** and the second outer edge bead **355** either alone or in combination with the first cladding bead **503** and the second cladding bead **504** can include high stress and high thermal gradient characteristics that can cause the glass ribbon **103** to crack, fracture, and fail when separating a glass sheet **104** from the glass ribbon **103**. Thus, by removing the first edge portion **301a** and the second edge portion **301b** from the central portion **303** of the glass ribbon **103**, the associated high stress and high thermal gradient characteristics of the first edge portion **301a** and the second edge portion **301b** that can cause the glass ribbon **103** to crack, fracture, and fail when separating a glass sheet **104** from the glass ribbon **103** can be entirely eliminated from the glass manufacturing process and instead replaced with a smooth, defect-free edge that, in some embodiments, can be flame-polished, tempered, and encapsulated with at least one of the first cladding layer **501** and the second cladding layer **502**.

[0090] It will be appreciated that the various disclosed embodiments may involve particular features, elements or steps that are described in connection with that particular embodiment. It will also be appreciated that a particular feature, element or step, although described in relation to one particular embodiment, may be interchanged or combined with alternate embodiments in various non-illustrated combinations or permutations.

[0091] It is to be understood that, as used herein the terms "the," "a," or "an," mean "at least one," 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.

[0092] Ranges can be expressed herein as from "about" one particular value, and/or to "about" another particular value. When such a range is expressed, embodiments include from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent "about," it will be understood that the particular value forms another aspect. 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.

[0093] Unless otherwise expressly stated, it is in no way intended that any method set forth herein be construed as requiring that its steps be performed in a specific order. Accordingly, where a method claim does not actually recite an order to be followed by its steps or it is not otherwise specifically stated in the claims or descriptions that the steps are to be limited to a specific order, it is no way intended that any particular order be inferred.

[0094] While various features, elements or steps of particular embodiments may be disclosed using the transitional phrase "comprising," it is to be understood that alternative embodiments, including those that may be described using the transitional phrases "consisting" or "consisting essentially of," are implied. Thus, for example, implied alternative embodiments to an apparatus that comprises A+B+C include embodiments where an apparatus consists of A+B+C and embodiments where an apparatus consists essentially of A+B+C.

[0095] It will be apparent to those skilled in the art that various modifications and variations can be made to the present disclosure without departing from the spirit and scope of the disclosure. Thus, it is intended that the present disclosure cover the modifications and variations of this disclosure provided they come within the scope of the appended claims and their equivalents.

CLAIMS

What is claimed is:

1. A method of manufacturing glass comprising:

forming a glass ribbon from a quantity of molten material;

drawing the glass ribbon in a draw direction, wherein the glass ribbon comprises a pair of opposed edge portions and a central portion laterally spanning between the opposed edge portions; and

separating a first edge portion of the pair of opposed edge portions from the central portion by cutting through the glass ribbon while the glass ribbon is being drawn in the draw direction, wherein

cutting through the glass ribbon creates a gap comprising a distance of from about 1 mm to about 20 mm between a cut edge of the central portion and a cut edge of the first edge portion.

2. The method of claim 1, wherein the gap is created when the glass ribbon is in a viscous state prior to the glass ribbon transitioning to an elastic state.

3. The method of claim 1, wherein separating the first edge portion from the central portion comprises cutting through the glass ribbon with a cutting torch.

4. The method of claim 3, wherein cutting through the glass ribbon with a cutting torch comprises contacting the glass ribbon with a flame produced by the cutting torch.

5. The method of claim 3, further comprising:

separating a second edge portion of the pair of opposed edge portions from the central portion by cutting through the glass ribbon with another cutting torch while the glass ribbon is being drawn in the draw direction.

6. The method of claim 5, wherein cutting through the glass ribbon with the other cutting torch creates another gap comprising a distance of from about 1 mm to about 20 mm between another cut edge of the central portion and a cut edge of the second edge portion.

7. The method of claim 1, wherein cutting through the glass ribbon provides the cut edge of the central portion with a cut edge bead comprising a thickness that is greater than a thickness of an interior portion of the central portion of the glass ribbon.

8. The method of claim 7, further comprising:

removing the cut edge bead from the interior portion of the central portion to provide a trimmed central portion.

9. The method of claim 1, wherein each of the opposed edge portions comprises an outer edge bead comprising a thickness that is greater than a thickness of an interior portion of the central portion of the glass ribbon.

10. The method of claim 9, wherein cutting through the glass ribbon provides the cut edge of the central portion with a cut edge bead comprising a thickness that is greater than the thickness of the outer edge bead of the first edge portion of the opposed edge portions.

11. The method of claim 1, further comprising:

separating a glass sheet from the central portion of the glass ribbon along a separation path that is transverse to the draw direction of the glass ribbon.

12. The method of claim 11, wherein cutting through the glass ribbon provides the cut edge of the central portion with a cut edge bead comprising a thickness that is greater than a thickness of an interior portion of the central portion of the glass ribbon, wherein the glass sheet comprises the cut edge bead, and wherein the method further comprises:

removing the cut edge bead from the glass sheet to provide a trimmed glass sheet.

13. The method of claim 1, wherein the glass ribbon comprises a first cladding layer on a first major surface of the glass ribbon and a second cladding layer on a second major surface of the glass ribbon, and wherein separating the first edge portion from the central portion further comprises cutting through the first cladding layer and the second cladding layer while the glass ribbon is being drawn in the draw direction.

14. The method of claim 13, wherein separating the first edge portion from the central portion comprises cutting through the first cladding layer and the second cladding layer with a cutting torch.

15. The method of claim 14, wherein cutting through the first cladding layer and the second cladding layer with a cutting torch comprises contacting at least one of the first cladding layer and the second cladding layer with a flame produced by the cutting torch.

16. The method of claim 13, wherein cutting through the glass ribbon, the first cladding layer, and the second cladding layer provides the cut edge of the central portion of the glass ribbon with a cut edge bead comprising a thickness that is greater than a thickness of an interior portion of the central portion of the glass ribbon.

17. The method of claim 13, wherein cutting through the glass ribbon, the first cladding layer, and the second cladding layer provides the cut edge of the central portion of the glass ribbon with a cut edge bead that is encapsulated by at least one of the first cladding layer and the second cladding layer.

18. A glass manufacturing apparatus comprising:

a glass former to form a glass ribbon from a quantity of molten material; and

a cutting torch oriented to cut through the glass ribbon to separate a first edge portion from a central portion of the glass ribbon while the glass ribbon is drawn from the glass former.

19. The glass manufacturing apparatus of claim 18, further comprising:

another cutting torch oriented to cut through the glass ribbon to separate a second edge portion from the central portion of the glass ribbon while the glass ribbon is drawn from the glass former.

20. The glass manufacturing apparatus of claim 18, wherein the cutting torch is oriented to direct a flame from the cutting torch to contact a glass ribbon being drawn from the glass former.

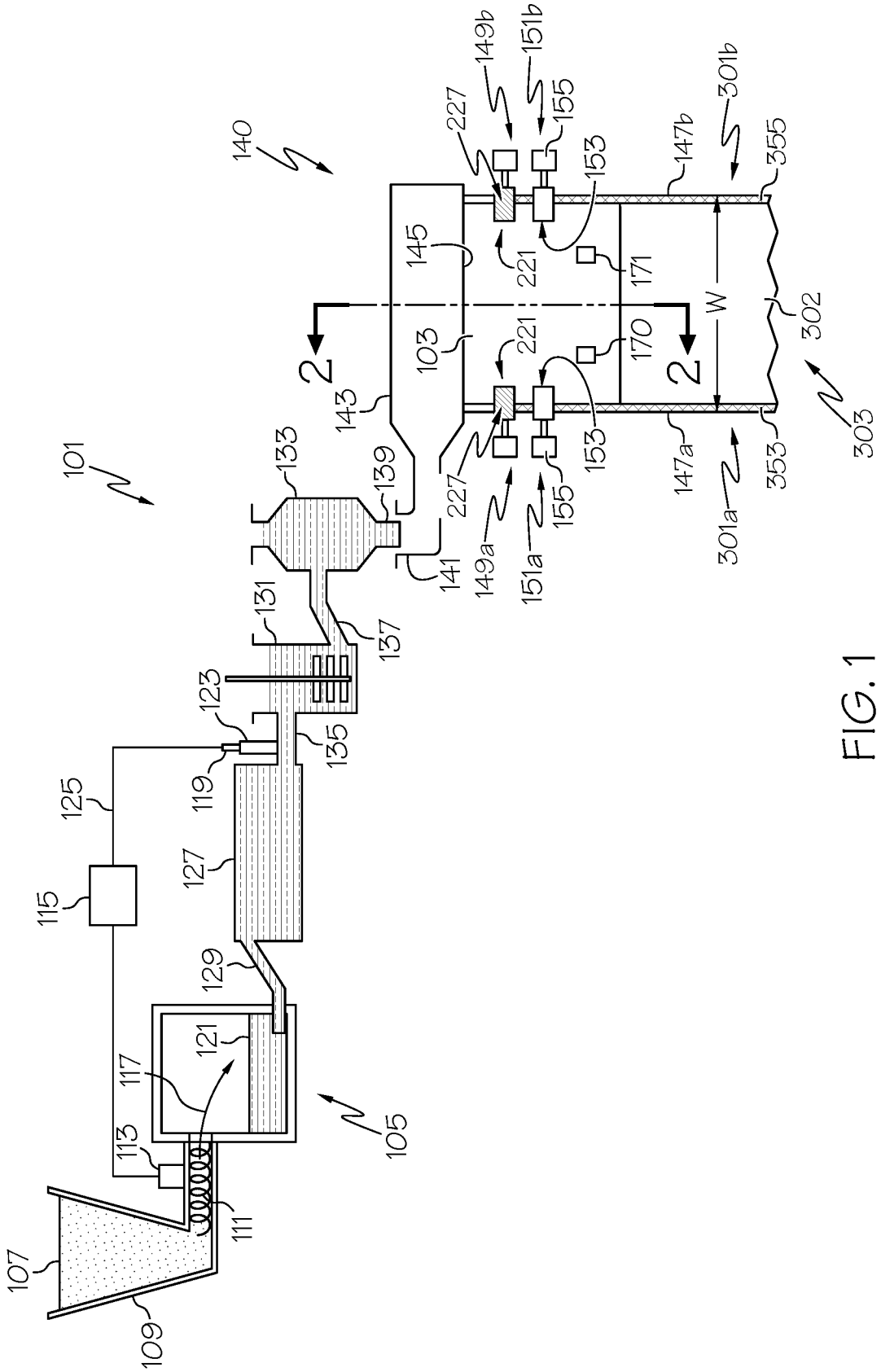
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FIG. 1

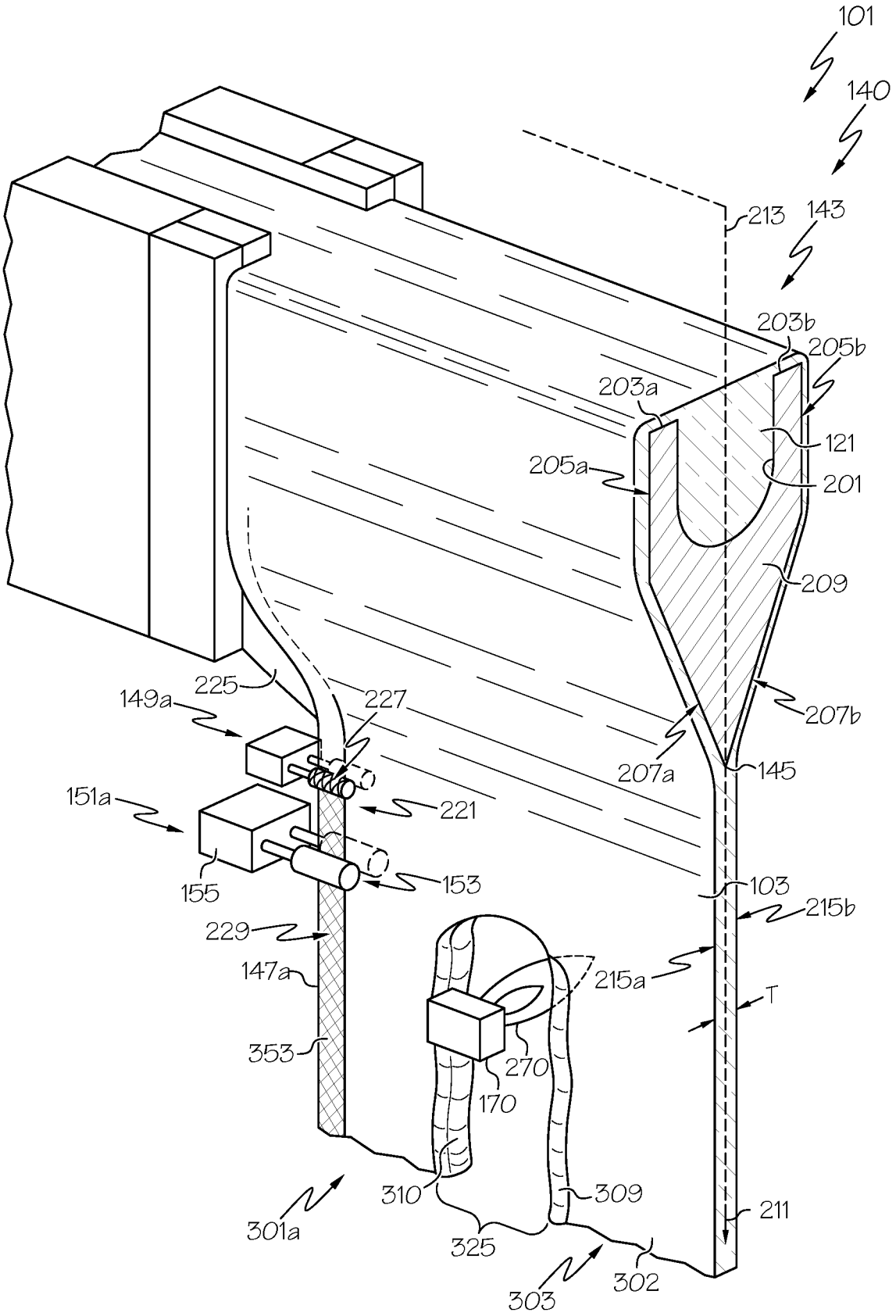
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FIG. 2

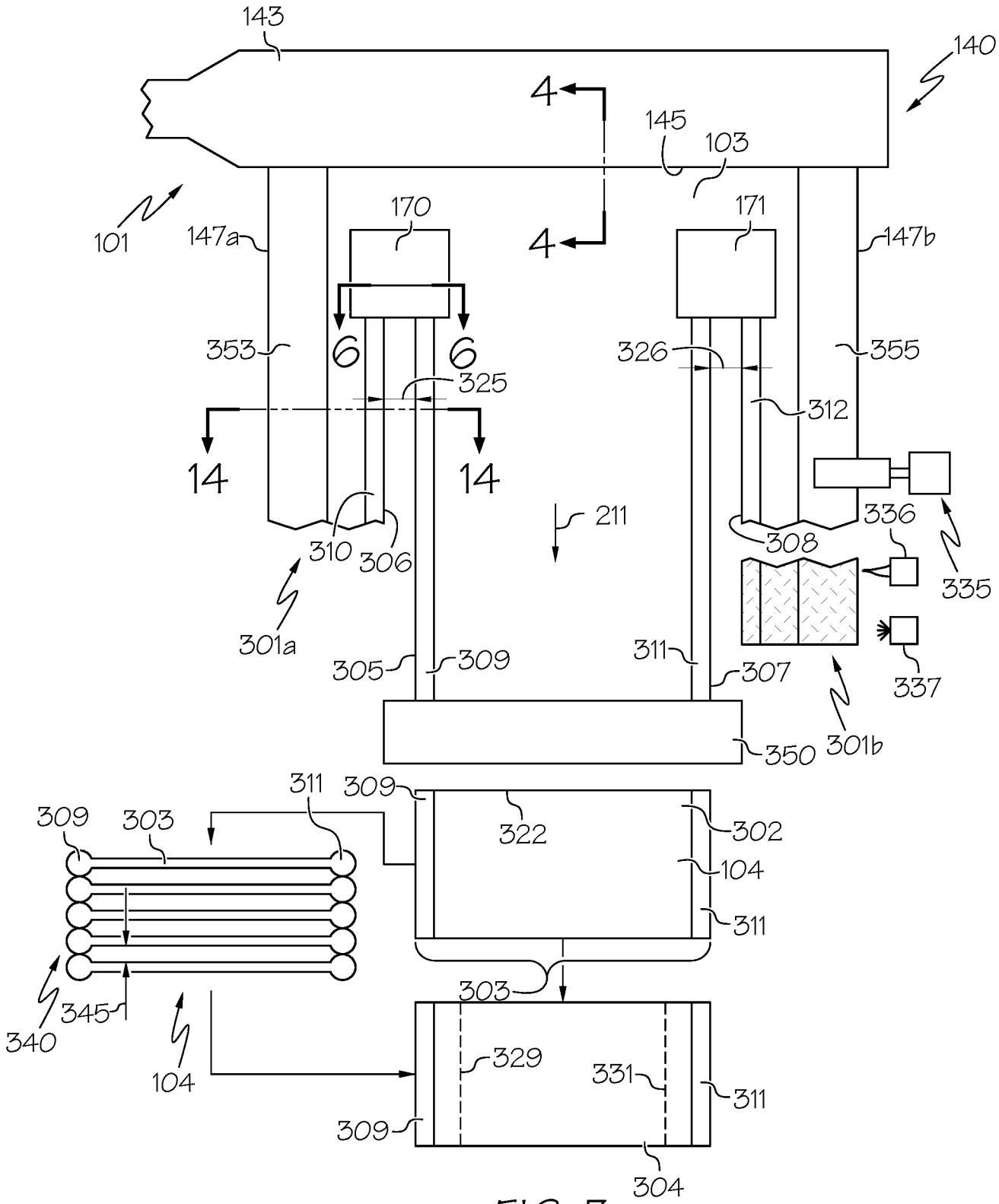
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FIG. 3

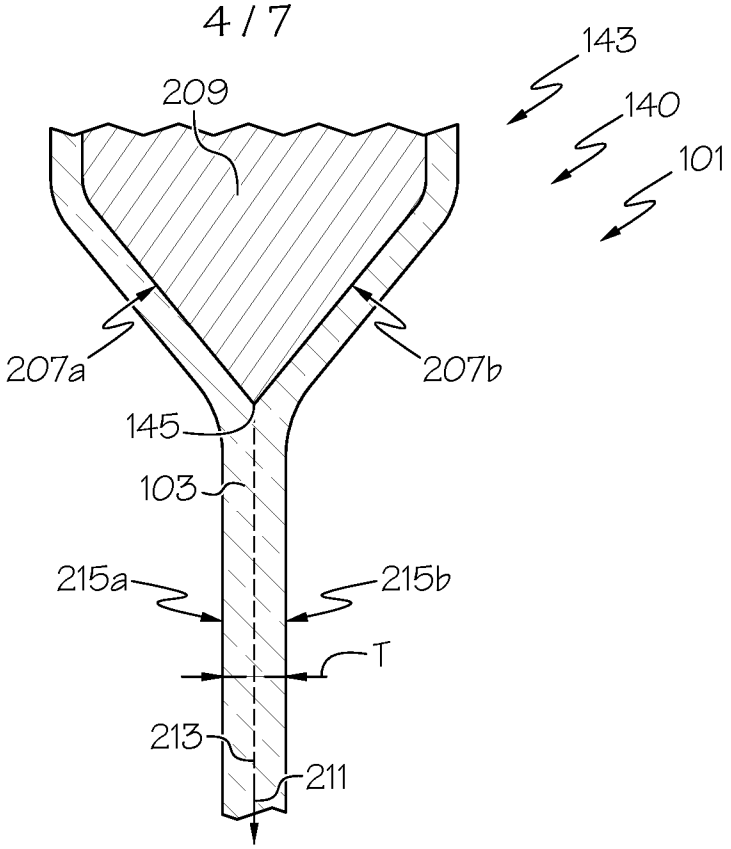
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FIG. 4

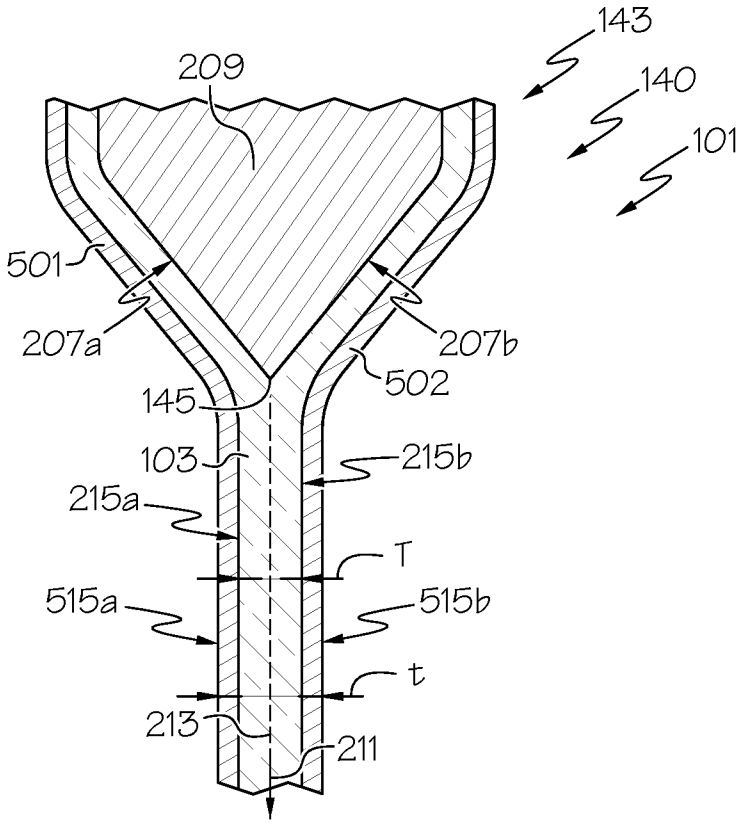
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FIG. 5

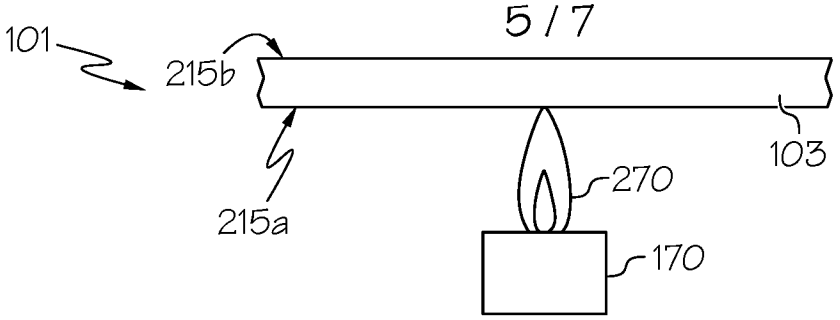

FIG. 6

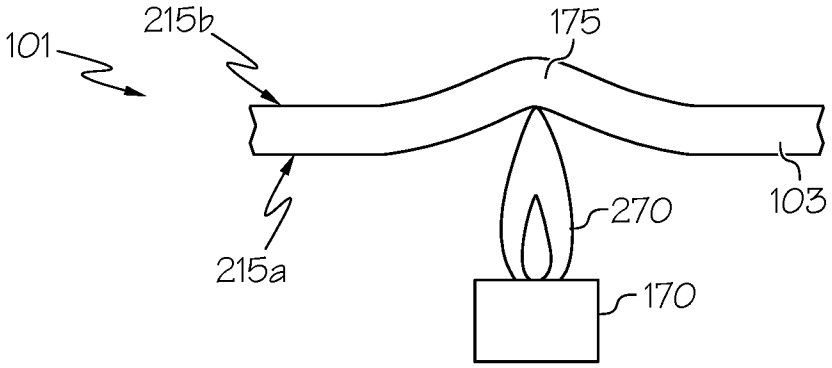

FIG. 7

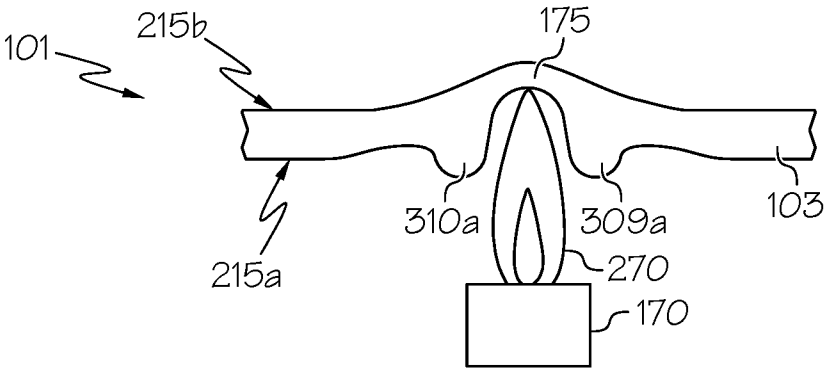

FIG. 8

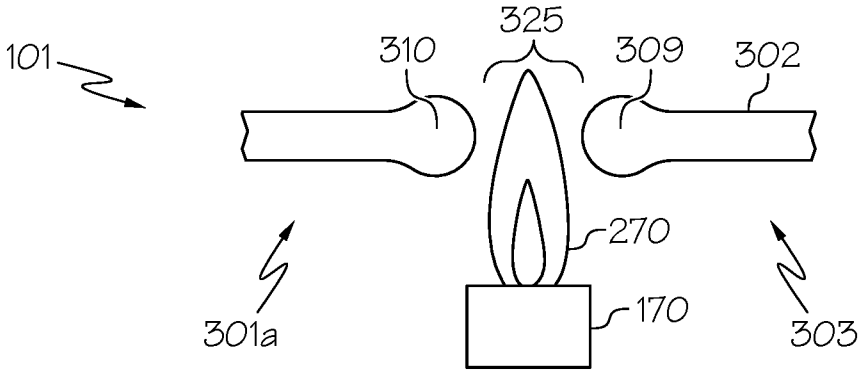

FIG. 9

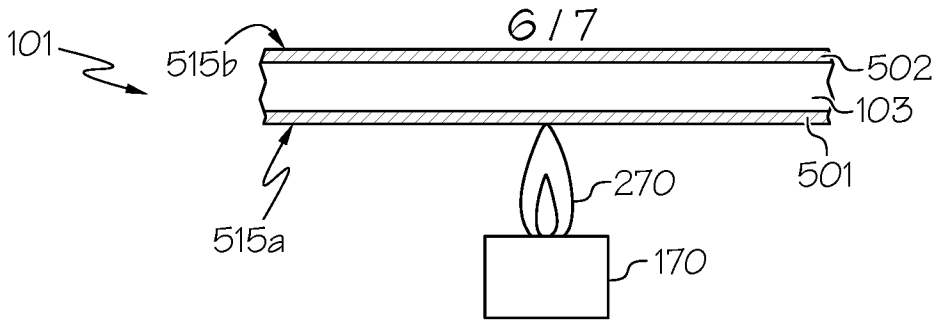

FIG. 10

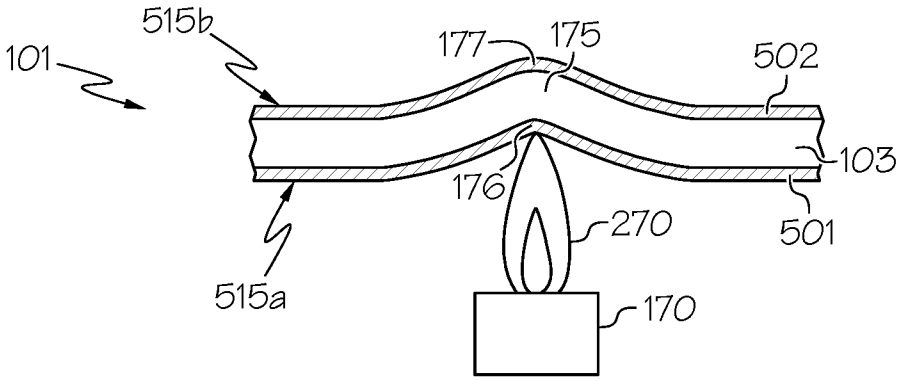

FIG. 11

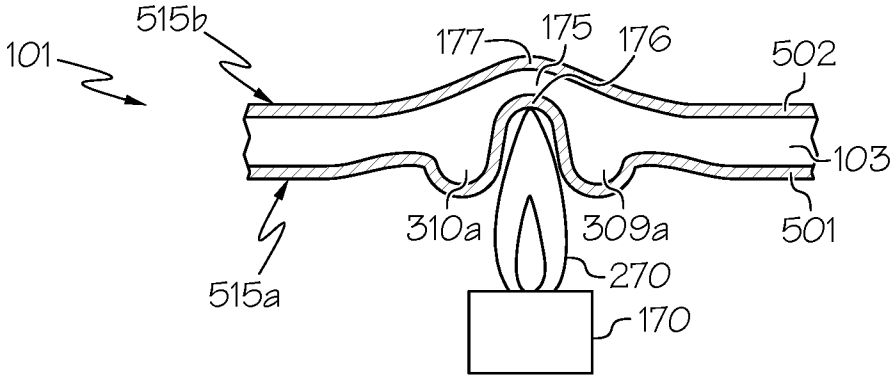

FIG. 12

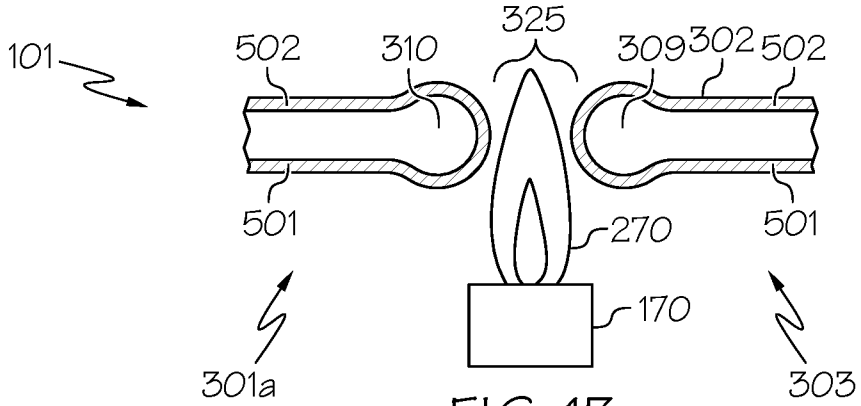

FIG. 13

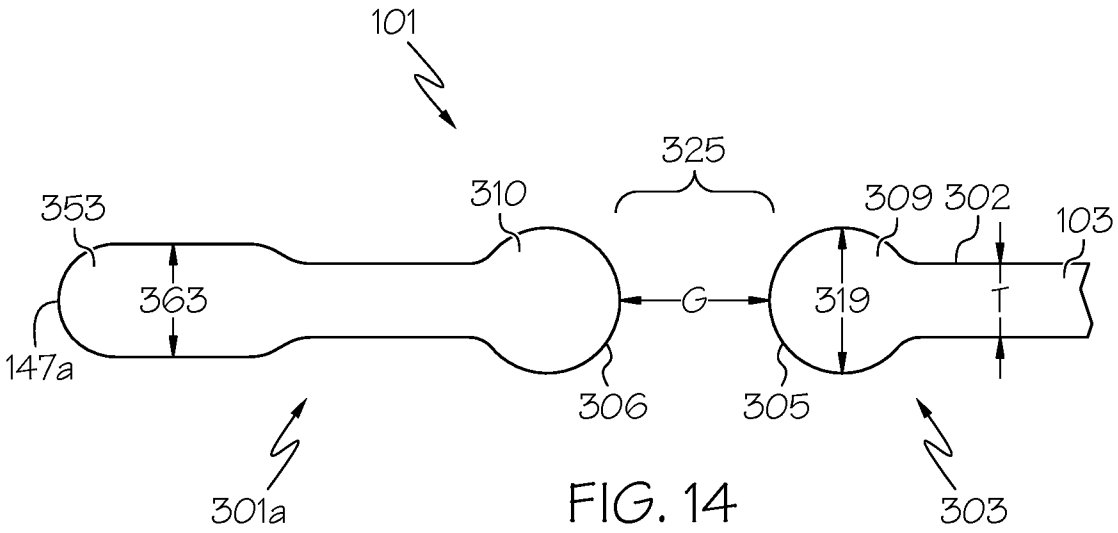
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FIG. 14

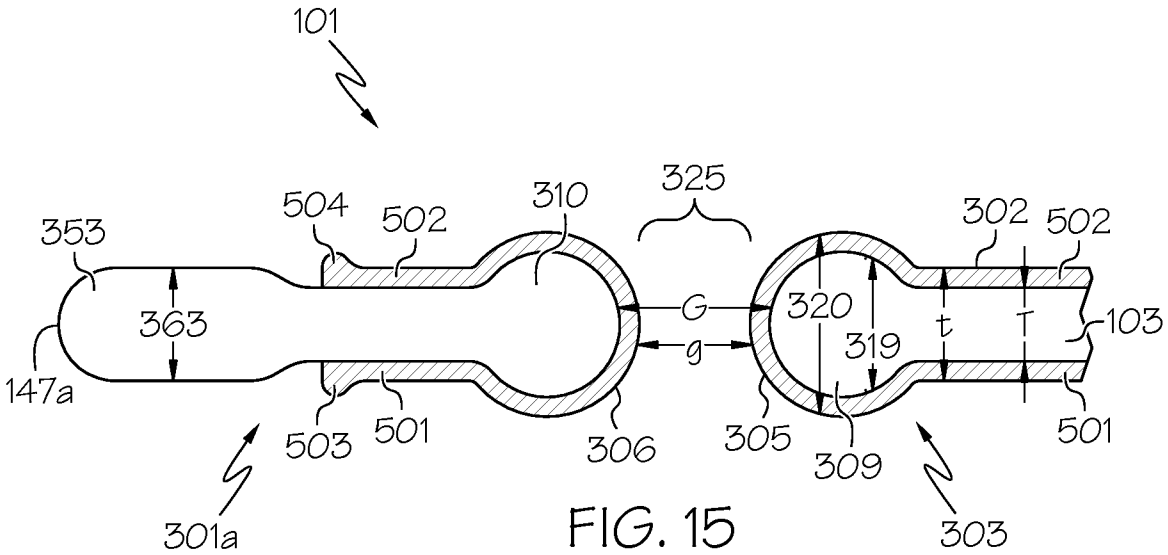
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FIG. 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/023716

A. CLASSIFICATION OF SUBJECT MATTER

C03B 17/06(2006.01)i, C03B 33/08(2006.01)i, C03B 33/10(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C03B 17/06; C03B 37/012; C03B 37/16; C03B 37/018; B29C 35/08; C03B 33/08; C03B 33/10

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: glass, cutting, gap, torch, flame

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2014-0216107 A1 (BRUNELLO, PIERRE et al.) 07 August 2014 See claims 1, 24; paragraphs [0054]-[0057], [0069]-[0071]; figures 1, 2, 7.	18-20
A		1-17
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05 July 2017 (05.07.2017)	**05 July 2017 (05.07.2017)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

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