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ABSTRACT

Methods of fabricating a glass ribbon comprise the step of bending a glass ribbon in a cutting zone to provide a bent target segment with a bent orientation in the cutting zone. The methods further include the step of severing at least one of the edge portions from the central portion of the bent target segment within the cutting zone. Further methods are provided including the step of bending a glass ribbon in a bending zone downstream from a downward zone, wherein the glass ribbon includes an upwardly concave surface through the bending zone. The methods further include the step of severing at least one of the edge portions from the central portion of a target segment within the bending zone.

CLAIMS

What is claimed is:

1. A method of fabricating a glass ribbon comprising the steps of:
 - (I) providing a source of the glass ribbon with a pair of opposed edge portions and a central portion laterally spanning between the opposed edge portions;
 - (II) traversing the glass ribbon in a downward direction relative to the source through a downward zone;
 - (III) bending the glass ribbon in a bending zone downstream from the downward zone, wherein the glass ribbon includes an upwardly concave surface through the bending zone;
 - (IV) traversing the glass ribbon into a cutting zone downstream from the bending zone;
 - (V) bending the glass ribbon in the cutting zone to provide a bent target segment with a bent orientation in the cutting zone; and
 - (VI) severing at least one of the edge portions from the central portion of the bent target segment within the cutting zone.
2. The method of claim 1, further including the step of supporting the bent target segment with a curved air bar while severing at least one of the edge portions from the central portion of the bent target segment within the cutting zone.
3. The method of claim 1 or claim 2, wherein during step (V) the glass ribbon is bent such that the bent orientation of the target segment includes an upwardly facing convex surface.
4. The method of claim 3, wherein the step of severing at least one of the edge portions includes a step of heating a portion of the upwardly facing convex surface of the bent target segment with an optical delivery apparatus.

5. The method of claim 4, wherein the step of severing at least one of the edge portions further includes cooling the heated portion of the upwardly facing convex surface with a coolant fluid.
6. The method of claim 4, wherein the step of heating the portion of the upwardly facing convex surface includes shaping a laser beam of the optical delivery apparatus to contact the portion of the convex surface with an elongated radiation zone of the laser beam.
7. The method of claim 3, further including the step of supporting the bent target segment with an upwardly facing convex support surface of an air bar while severing at least one of the edge portions from the central portion of the bent target segment within the cutting zone.
8. The method of claim 1 or claim 2, wherein during step (V) the glass ribbon is bent such that the bent orientation of the target segment includes an upwardly facing concave surface.
9. The method of claim 8, wherein the step of severing at least one of the edge portions includes a step of heating a portion of the upwardly facing concave surface of the target segment with an optical delivery apparatus.
10. The method of claim 9, wherein the step of severing at least one of the edge portions further includes cooling the heated portion of the upwardly facing concave surface with a coolant fluid.
11. The method of claim 9, wherein the step of heating the portion of the upwardly facing concave surface includes shaping a laser beam from the optical delivery apparatus

to contact the portion of the concave surface with an elongated radiation zone of the laser beam.

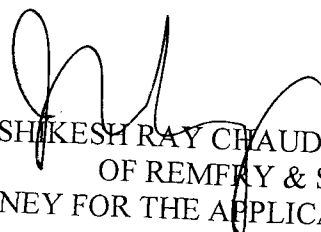
12. The method of claim 8, further including the step of supporting the bent target segment with an upwardly facing concave support surface of an air bar while severing at least one of the edge portions from the central portion of the bent target segment within the cutting zone.

13. The method of claim 1 or claim 2, wherein the source comprises a coiled spool of glass ribbon and the method further includes the step of uncoiling the glass ribbon from the coiled spool of glass ribbon to traverse the glass ribbon in the downward direction during step (II).

14. The method of claim 1 or claim 2, wherein the source comprises a down draw glass forming apparatus and the method further includes the step of fusion down drawing the glass ribbon from the down draw glass forming apparatus to traverse the glass ribbon in the downward direction during step (II).

15. The method of claim 1 or claim 2, further including the step of coiling the central portion of the glass ribbon into a storage roll after step (VI).

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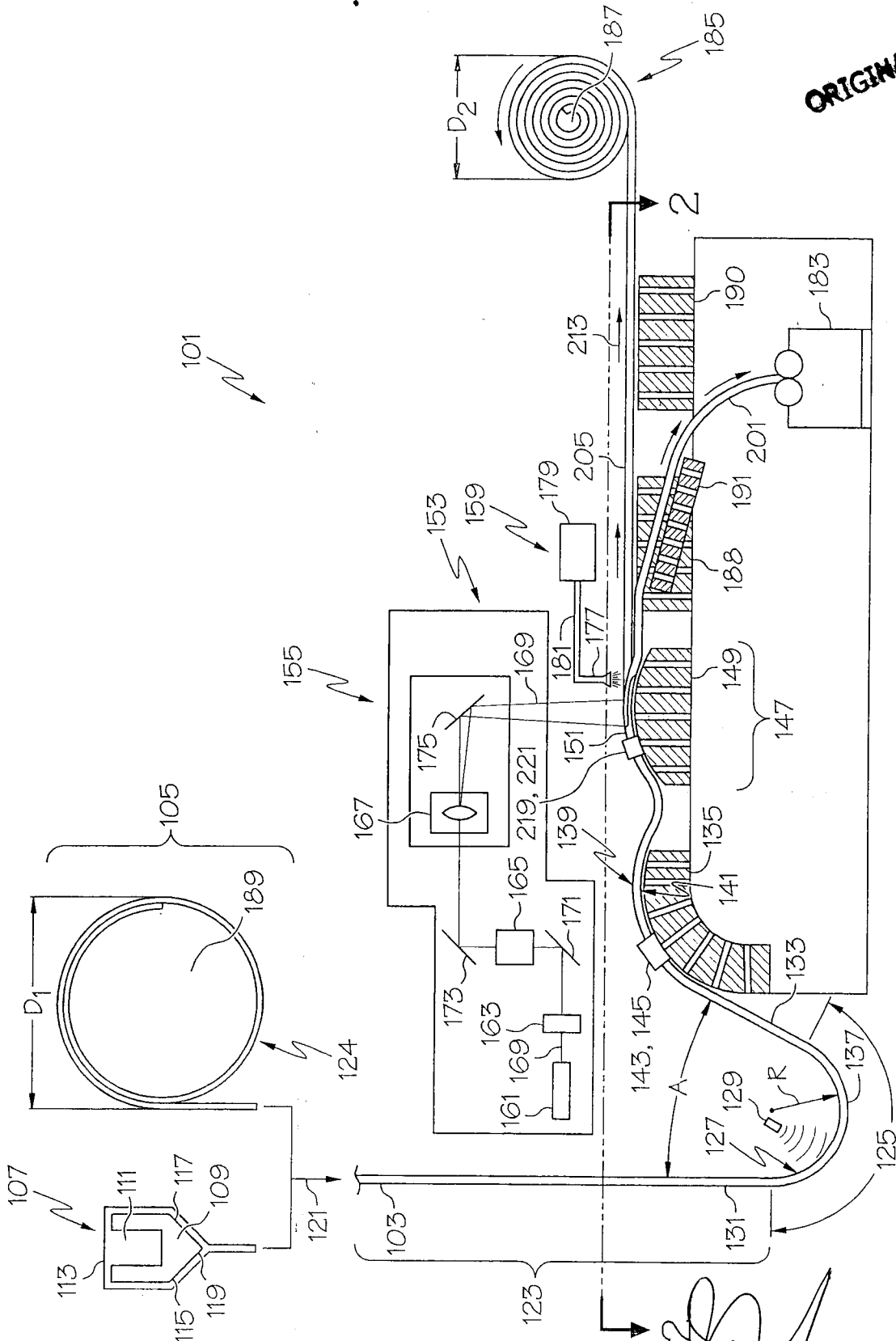


FIG. 1

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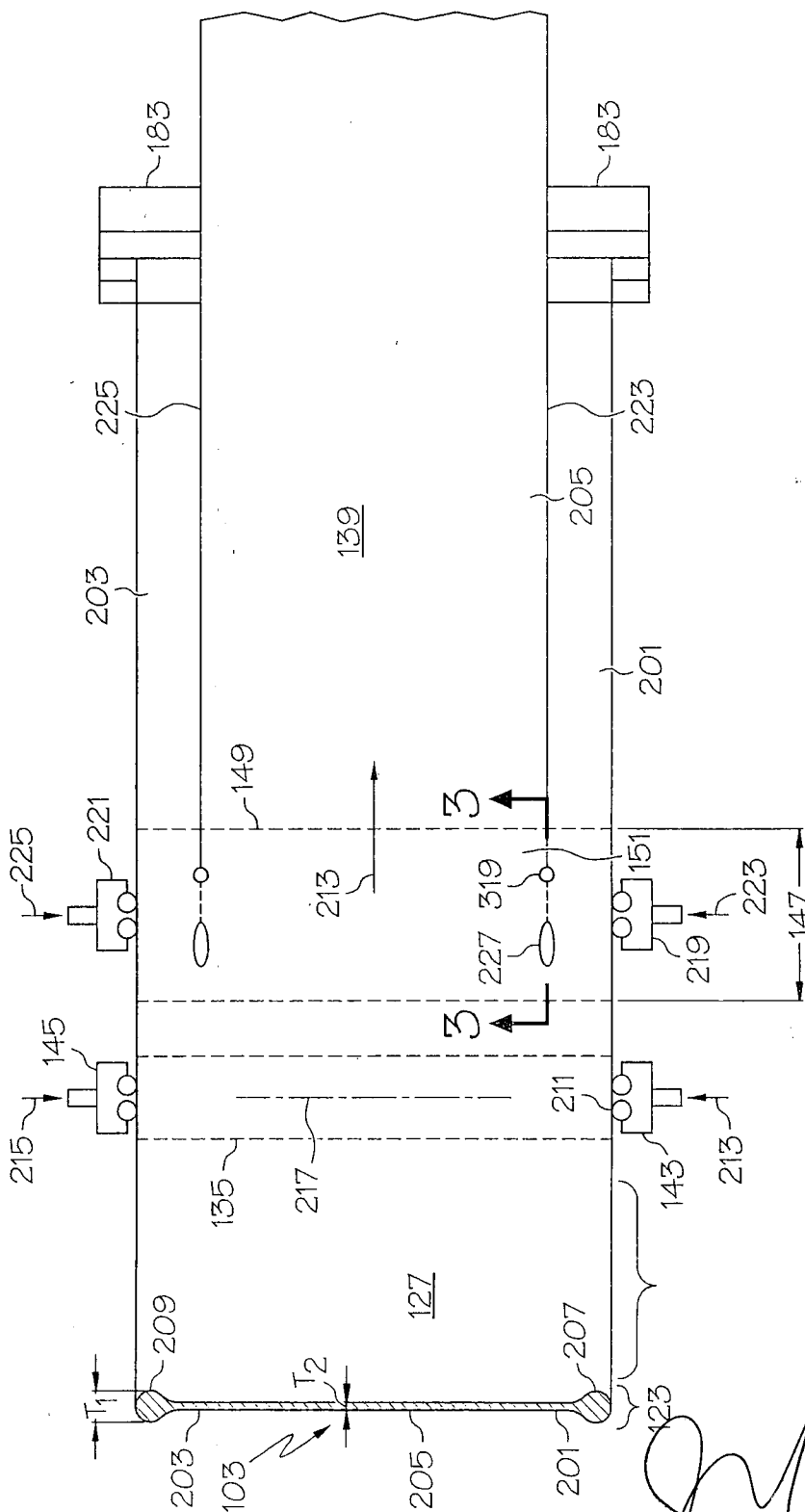


FIG. 2

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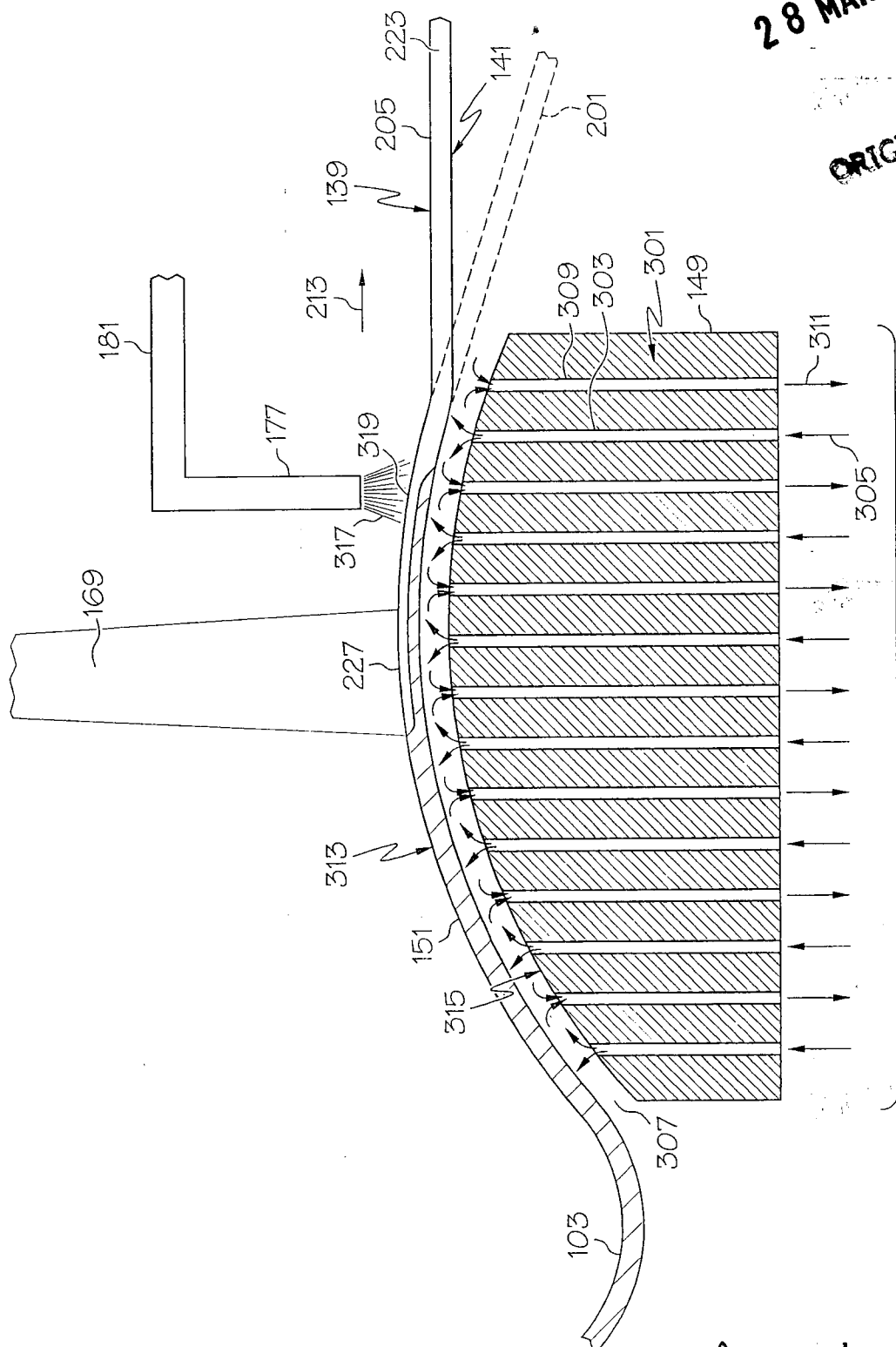


FIG. 3

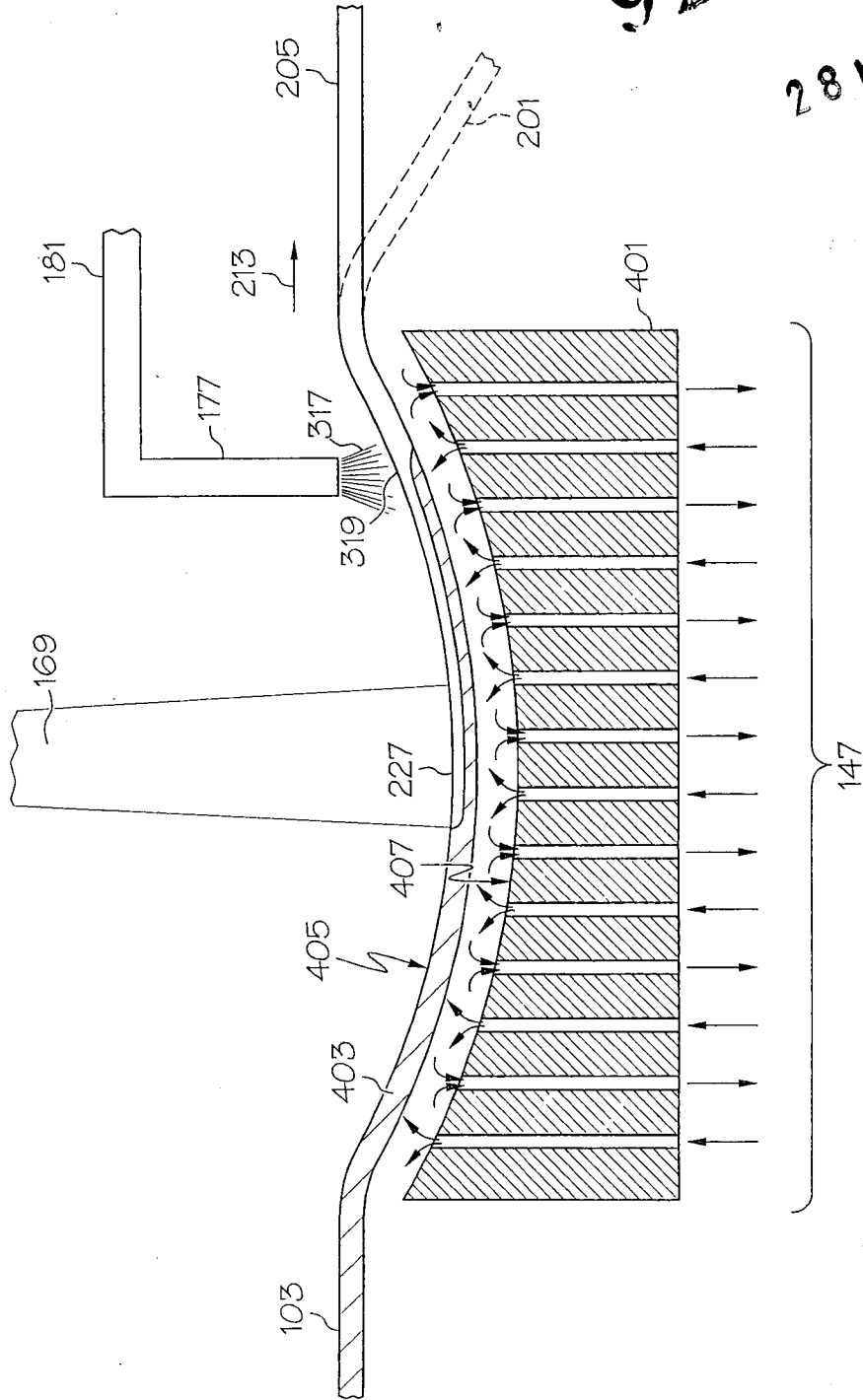
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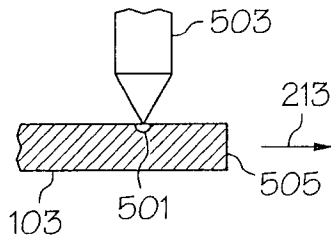


FIG. 5

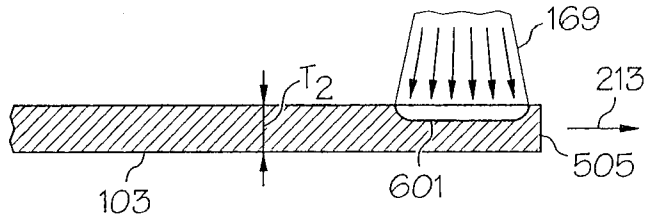


FIG. 6

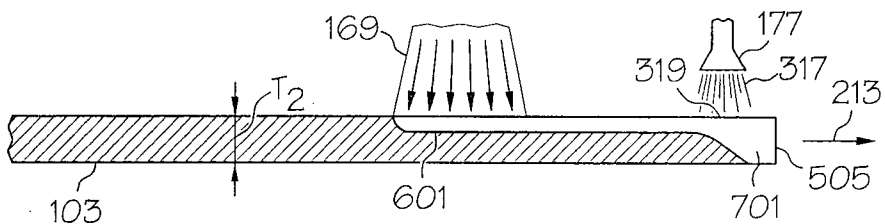


FIG. 7

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METHODS OF FABRICATING A GLASS RIBBON

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 61/469321 filed on March 30, 2011, and claims the benefit of priority under 35 U.S.C. §120 of the U.S. Application Serial No. 13/182029 on July 13, 2011 the content of which are relied upon and incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present invention relates generally to a methods of fabricating a glass ribbon, and more particularly to methods of fabricating a glass ribbon including the step of severing at least one edge portion from a central portion of the glass ribbon.

BACKGROUND

[0003] Glass manufacturing apparatus are commonly used to form various glass products such as LCD sheet glass. It is known to manufacture sheet glass by downwardly flowing molten glass over a forming wedge and using edge rollers to engage beads formed at opposite edge portions of a glass ribbon.

SUMMARY

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

[0005] In one example aspect, a method of fabricating a glass ribbon comprises the step of (I) providing a source of the glass ribbon with a pair of opposed edge portions and a central portion laterally spanning between the opposed edge portions. The method can further include the steps of: (II) traversing the glass ribbon in a downward direction relative to the source through a downward zone; and (III) bending the glass ribbon in a bending zone downstream from the downward zone, wherein the glass ribbon includes an upwardly concave surface through the bending zone. The method further includes the steps of (IV) traversing the glass ribbon into a cutting zone downstream from the bending zone; and (V) bending the glass ribbon in the cutting zone to provide a bent target segment with a bent orientation in the cutting zone. The method also includes the step of: (VI) severing at least

one of the edge portions from the central portion of the bent target segment within the cutting zone.

[0006] In accordance with one embodiment of the aspect, the method further includes the step of supporting the bent target segment with a curved air bar while severing at least one of the edge portions from the central portion of the bent target segment within the cutting zone.

[0007] In accordance with another embodiment of the aspect, during step (V) the glass ribbon is bent such that the bent orientation of the target segment includes an upwardly facing convex surface.

[0008] In accordance with still another embodiment of the aspect, the step of severing at least one of the edge portions includes a step of heating a portion of the upwardly facing convex surface of the bent target segment with an optical delivery apparatus.

[0009] In accordance with yet another example embodiment of the aspect, the step of severing at least one of the edge portions further includes cooling the heated portion of the upwardly facing convex surface with a coolant fluid.

[0010] In accordance with still another example embodiment of the aspect, the step of heating the portion of the upwardly facing convex surface includes shaping a laser beam of the optical delivery apparatus to contact the portion of the convex surface with an elongated radiation zone of the laser beam.

[0011] In accordance with another example embodiment of the aspect, the method includes the step of supporting the bent target segment with an upwardly facing convex support surface of an air bar while severing at least one of the edge portions from the central portion of the bent target segment within the cutting zone.

[0012] In accordance with another embodiment of the aspect, during step (V), the glass ribbon is bent such that the bent orientation of the target segment includes an upwardly facing concave surface.

[0013] In accordance with still another embodiment of the aspect, the step of severing at least one of the edge portions includes a step of heating a portion of the upwardly facing concave surface of the target segment with an optical delivery apparatus.

[0014] In accordance with yet another embodiment of the aspect, the step of severing at least one of the edge portions further includes cooling the heated portion of the upwardly facing concave surface with a coolant fluid.

[0015] In still another example embodiment of the aspect, the step of heating the portion of the upwardly facing concave surface includes shaping a laser beam from the optical delivery apparatus to contact the portion of the concave surface with an elongated radiation zone of the laser beam.

[0016] In accordance with still another embodiment of the aspect, the method can include the step of supporting the bent target segment with an upwardly facing concave support surface of an air bar while severing at least one of the edge portions from the central portion of the bent target segment within the cutting zone.

[0017] In accordance with yet another embodiment of the aspect, the source comprises a coiled spool of glass ribbon and the method further includes the step of uncoiling the glass ribbon from the coiled spool of glass ribbon to traverse the glass ribbon in the downward direction during step (II).

[0018] In accordance with still another embodiment of the aspect, the source comprises a down draw glass forming apparatus and the method further includes the step of fusion down drawing the glass ribbon from the down draw glass forming apparatus to traverse the glass ribbon in the downward direction during step (II).

[0019] In accordance with still another embodiment of the aspect, the method further includes the step of coiling the central portion of the glass ribbon into a storage roll after step (VI).

[0020] In accordance with another example aspect, a method of fabricating a glass ribbon comprises the step of: (I) providing a source of the glass ribbon with a pair of opposed edge portions and a central portion laterally spanning between the opposed edge portions. The method further includes the step of: (II) traversing the glass ribbon in a downward direction relative to the source through a downward zone. The method further includes the steps of: (III) bending the glass ribbon in a bending zone downstream from the downward zone, wherein the glass ribbon includes an upwardly concave surface through the bending

zone; and (IV) severing at least one of the edge portions from the central portion of a target segment within the bending zone.

[0021] In accordance with one embodiment of the aspect, the source comprises a coiled spool of glass ribbon and the method further includes the step of uncoiling the glass ribbon from the coiled spool of glass ribbon to traverse the glass ribbon in the downward direction during step (II).

[0022] In accordance with another embodiment of the aspect, the source comprises a down draw glass forming apparatus and the method further includes the step of fusion down drawing the glass ribbon from the down draw glass forming apparatus to traverse the glass ribbon in the downward direction during step (II).

[0023] In accordance with one embodiment of the aspect, the method further includes the step of coiling the central portion of the glass ribbon into a coiled spool of glass ribbon after step (IV).

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] These and other aspects are better understood when the following detailed description is read with reference to the accompanying drawings, in which:

[0025] **FIG. 1** illustrates a schematic view of an example apparatus for fabricating a glass ribbon;

[0026] **FIG. 2** is a sectional view of the apparatus along line 2-2 of **FIG. 1**;

[0027] **FIG. 3** is a sectional view of the apparatus along line 3-3 of **FIG. 2**, illustrating an example cutting support member with an upwardly facing convex support surface;

[0028] **FIG. 4** is a sectional view of the apparatus similar to **FIG. 3**, but illustrating another example cutting support member with an upwardly facing concave support surface;

[0029] **FIG. 5** illustrates an example scribe forming an initial crack in the glass ribbon;

[0030] **FIG. 6** illustrates an elongated radiation zone of a laser beam propagating the initial crack from **FIG. 5** into an elongated crack portion extending partially through the thickness of the glass ribbon;

[0031] **FIG. 7** illustrates a coolant jet propagating the elongated crack portion of **FIG. 6** completely through the thickness of the glass ribbon to sever the corresponding end portions from the central portion of the glass ribbon; and

[0032] **FIG. 8** illustrates a schematic view of another example apparatus for fabricating a glass ribbon.

DETAILED DESCRIPTION

[0033] Examples will now be described more fully hereinafter with reference to the accompanying drawings in which example embodiments are shown. Whenever possible, the same reference numerals are used throughout the drawings to refer to the same or like parts. However, aspects may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein.

[0034] **FIG. 1** illustrates an apparatus **101** for fabricating a glass ribbon **103**. The glass ribbon **103** can be provided by a wide range of glass ribbon sources. **FIG. 1** illustrates two example sources **105** of glass ribbon **103** although other sources may be provided in further examples. For instance, as shown in **FIG. 1**, the source **105** of glass ribbon **103** can comprise a down draw glass forming apparatus **107**. As schematically shown, the down draw glass forming apparatus **107** can include a forming wedge **109** at the bottom of a trough **111**. In operation, molten glass **113** can overflow the trough **111** and flow down opposite sides **115**, **117** of the forming wedge **109**. The two sheets of molten glass are subsequently fused together as they are drawn off the root **119** of the forming wedge **109**. As such, the glass ribbon **103** may be fusion down drawn to traverse in a downward direction **121** off the root **119** of the forming wedge **109** and directly into a downward zone **123** positioned downstream from the down draw glass forming apparatus **107**.

[0035] As shown by the cross section of **FIG. 2**, the glass ribbon **103** can include a pair of opposed edge portions **201**, **203** and a central portion **205** spanning between the opposed edge portions **201**, **203**. Due to the down draw fusion process, the edge portions **201**, **203** of the glass ribbon may have corresponding beads **207**, **209** with a thickness " T_1 " that is greater than a thickness " T_2 " of the central portion **205** of the glass ribbon **103**. The apparatus **101** can be designed to process glass ribbons **103** with a thin central portion **205**, such as glass ribbons with a thickness " T_2 " in a range of from about 20 microns to about 300

microns, such as from about 50 microns to about 300 microns, such as from about 85 microns to about 150 microns although glass ribbons with other thicknesses may be processed in further examples.

[0036] Turning back to **FIG. 1**, another example source **105** of glass ribbon **103** can comprise a coiled spool **124** of glass ribbon **103**. For example, glass ribbon **103** may be wound into the coiled spool **124** after being drawn into a glass ribbon, for example, with the down draw glass forming apparatus **107**. The greater thickness of the edge portions **201**, **203** may increase the minimum bend radius to avoid cracking or breaking the glass ribbon. As such, if coiled, the glass ribbon **103** may be coiled with a relatively large bend radius such that a given length of glass ribbon **103** would require a coiled spool **124** with a relatively large diameter "**D₁**". Thus, if the source **105** comprises the coiled spool **124**, the glass ribbon **103** may be uncoiled from the coiled spool **124** of glass ribbon **103** to traverse the glass ribbon **103** in the downward direction **121** into the downward zone **123**.

[0037] The apparatus can also include a bending zone **125** downstream from the downward zone **123**. In the bending zone **125**, the apparatus **101** can be designed to permit the glass ribbon **103** to travel through a curved path such that an upper surface **127** of the glass ribbon **103** comprises an upwardly concave surface as the ribbon bends through a radius "**R**" within the bending zone **125**. The radius "**R**" may be greater than a minimum bend radius of the glass ribbon **103** to avoid stress concentrations in the glass ribbon **103**. The glass ribbon **103** may extend through various arcs within the bending zone **125** such that the a pre-bending portion **131** of the glass ribbon **103** entering the bending zone **125** can extend at various angles with respect to a post-bending portion **133** of the glass ribbon **103**. For example, as shown in **FIG. 1**, the angle "**A**" between the pre-bending portion **131** and the post-bending portion **133** can comprise an acute angle although angles of 90° or more may be provided in further examples while still providing the upwardly concave surface **127**.

[0038] The apparatus **101** can further include an optional bending support member **135** in examples where the elevation of a lower portion **137** of the glass ribbon within the bending zone **125** is lower than a lateral travel elevation of the glass ribbon passing through support portions leading to a cutting zone **147**. The bending support member **135**, if provided, can comprise a non-contact support member **135** designed to support the glass

ribbon **103** without touching the opposed faces **139**, **141** of the central portion **205** of the glass ribbon **103**. For example, the bending support member **135** can comprise one or more curved air bars configured to provide a cushion of air to space the glass ribbon from contacting the bending support member **135**.

[0039] Examples of the apparatus **101** can include lateral guides **143**, **145** to help orient the glass ribbon **103** in the correct lateral position relative to a travel direction **213** of the glass ribbon **103**. For example, as schematically shown in **FIG. 2**, the lateral guides can each comprise rollers **211** configured to engage a corresponding one of the opposed edge portions **201**, **203**. Corresponding forces **213**, **215** applied to the edge portions **201**, **203** by the corresponding lateral guides **143**, **145** can help properly shift and align the glass ribbon **103** in the proper lateral orientation along a direction of an axis **217** transverse to the travel direction **213** of the glass ribbon **103**.

[0040] As further illustrated, the lateral guides **143**, **145** can be designed to engage the edge portions **201**, **203** without engaging the central portion **205** of the glass ribbon **103**. As such, the pristine surfaces of the opposed faces **139**, **141** of the central portion **205** of the glass ribbon **103** can be maintained while avoiding undesired scratching or other surface contamination that might otherwise occur if the lateral guides **143**, **145** were to engage either of the opposed faces **139**, **141** of the central portion **205** of the glass ribbon **103**. Moreover, the lateral guides **143**, **145** may engage the glass ribbon **103** as it is being bent about the axis **217** transverse to the travel direction **213** of the glass ribbon **103**. Bending the glass ribbon **103** over the bending support member **135** can increase the rigidity of the glass ribbon **103** throughout the bend. As such, the lateral guides **143**, **145** can engage the glass ribbon **103** in a bent condition as the glass ribbon **103** passes over the bending support member **135**. The forces **213**, **215** applied by the lateral guides **143**, **145** are therefore less likely to buckle or otherwise disturb the stability of the glass ribbon profile when laterally aligning as the glass ribbon **103** passes over the bending support member **135**.

[0041] The apparatus can further include a cutting zone **147** downstream from the bending zone **125**. In one example, the apparatus **101** may include a cutting support member **149** configured to bend the glass ribbon **103** in the cutting zone **147** to provide a bent target segment **151** with a bent orientation in the cutting zone **147**. Bending the target segment **151**

within the cutting zone **147** can help stabilize the glass ribbon **103** during the cutting procedure. Such stabilization can help prevent buckling or disturbing the glass ribbon profile during the procedure of severing at least one of the opposed edge portions **201**, **203** from the central portion **205** of the glass ribbon **103**.

[0042] The cutting support member **149**, if provided, can comprise a non-contact cutting support member **149** designed to support the glass ribbon **103** without touching the opposed faces **139**, **141** of the glass ribbon **103**. For example, referring to **FIG. 3**, the non-contact cutting support member **149** can comprise one or more curved air bars configured to provide a cushion of air to space between the glass ribbon **103** and the cutting support member **149** to prevent the central portion **205** of the glass ribbon **103** from contacting the cutting support member **149**.

[0043] Referring to **FIG. 3**, the cutting support member **149** can be provided with a plurality of passages **301** configured to provide positive pressure ports **303** such that an air stream **305** can be forced through the positive pressure ports **303** toward the bent target segment **151** to create an air cushion **307** for a noncontact support of the bent target segment **151**. Optionally, the plurality of passages **301** can include negative pressure ports **309** such that an air stream **311** can be drawn away from the bent target segment **151** to create a suction to partially counteract the force from the air cushion created by the positive pressure ports **303**. A combination of positive and negative pressure ports can help stabilize the bent target segment **151** throughout the cutting procedure. Indeed, the positive pressure ports **303** can help maintain a desired air cushion **307** height between the central portion **205** of the glass ribbon **103** and the cutting support member **149**. At the same time, the negative pressure ports **309** can help pull the glass ribbon toward the cutting support member **149** to prevent the glass ribbon **103** from undulating or having portions of the bent target segment **151** from floating away from other portions of the target segment when traversing over the cutting support member **149** in the travel direction **213**.

[0044] Providing a bent target segment **151** in the cutting zone **147** can also increase the rigidity of the glass ribbon **103** throughout the cutting zone **147**. As such, as shown in **FIG. 2**, optional lateral guides **219**, **221** can engage the glass ribbon **103** in a bent condition as the glass ribbon **103** passes over the cutting support member **149** within the cutting zone

147. Forces **223, 225** applied by the lateral guides **219, 221** are therefore less likely to buckle or otherwise disturb the stability of the glass ribbon profile when laterally aligning as the glass ribbon **103** passes over the cutting support member **149**. The optional lateral guides **219, 221** can therefore be provided to fine tune the bent target segment **151** at the proper lateral orientation along a direction of the axis **217** transverse to the travel direction **213** of the glass ribbon **103**.

[0045] As set forth above, providing the bent target segment **151** in a bent orientation within the cutting zone **147** can help stabilize the glass ribbon **103** during the cutting procedure. Such stabilization can help prevent buckling or disturbing the glass ribbon profile during the procedure of severing at least one of the opposed edge portions **201, 203**. Moreover, the bent orientation of the bent target segment **151** can increase the rigidity of the target segment to allow optional fine tune adjustment of the lateral orientation of the bent target segment **151**. As such, relatively thin glass ribbons **103** can be effectively stabilized and properly laterally oriented without contacting the pristine opposed faces **139, 141** of the central portion **205** of the glass ribbon **103** during the procedure of severing at least one of the opposed edge portions **201, 203** from the central portion **205** of the glass ribbon **103**.

[0046] Increased stabilization and rigidity of the bent target segment **151** of the glass ribbon **103** can be achieved by bending the target segment to include an upwardly convex surface and/or an upwardly concave surface along a direction of the axis **217** transverse to the travel direction **213**. For example, as shown in **FIG. 3**, the bent target segment **151** includes a bent orientation with an upwardly facing convex surface **313**. Examples of the disclosure can involve supporting the bent target segment **151** with an upwardly facing convex support surface **315** of the cutting support member **149**, such as the illustrated air bar. As shown in **FIG. 2**, providing the cutting support member **149** with an upwardly facing convex support surface **315** can likewise bend the glass ribbon **103** in the cutting zone **147** to achieve the illustrated bent orientation with the upwardly facing convex surface **313**.

[0047] In another example, as shown in **FIG. 4**, another cutting support member **401** can be provided that is similar to the cutting support member **149** illustrated in **FIG. 3**. However, as shown in **FIG. 4**, the cutting support member **401** can be provided to support a bent target segment **403** in a bent orientation with an upwardly facing concave surface **405**.

Therefore, further examples of the disclosure can involve supporting the bent target segment **403** with an upwardly facing concave support **407** of the cutting support member **401** such as the illustrated air bar. As shown in **FIG. 4**, providing the cutting support member **401** with an upwardly facing concave support surface **407** can likewise bend the glass ribbon **103** in the cutting zone **147** to achieve the illustrated bent orientation with the upwardly facing concave surface **405**.

[0048] The apparatus **101** can further include a wide range of cutting devices configured to sever the edge portions **201**, **203** from the central portion **205** of the glass ribbon **103**. In one example, as shown in **FIG. 1**, one example glass cutting device **153** can include an optical delivery apparatus **155** for irradiating and therefore heating a portion of the upwardly facing surface of the bent target segment **151**. In one example, optical delivery apparatus **155** can comprise a radiation source such as the illustrated laser **161** although other radiation sources may be provided in further examples. The optical delivery apparatus **155** can further include a circular polarizer **163**, a beam expander **165**, and a beam shaping apparatus **167**.

[0049] The optical delivery apparatus **155** may further comprise optical elements for redirecting a beam of radiation (e.g., laser beam **169**) from the radiation source (e.g., laser **161**), such as mirrors **171**, **173** and **175**. The radiation source can comprise the illustrated laser **161** configured to emit a laser beam having a wavelength and a power suitable for heating the glass ribbon **103** at a location where the beam is incident on the glass ribbon **103**. In one embodiment, laser **161** can comprise a CO₂ laser although other laser types may be used in further examples.

[0050] The laser **161** may be configured to initially emit the laser beam **169** with a substantially circular cross section (i.e. the cross section of the laser beam at right angles to the longitudinal axis of the laser beam). The optical delivery apparatus **155** is operable to transform laser beam **169** such that the beam has a significantly elongated shape when incident on glass ribbon **103**. As shown in **FIG. 2**, the elongated shape can produce an elongated radiation zone **227** that may include the illustrated elliptical footprint although other configurations may be provided in further examples. The elliptical foot print can be

positioned on the upwardly facing convex or concave surface **313, 405** of the bent target segment **151, 403**.

[0051] The boundary of the elliptical footprint can be determined as the point at which the beam intensity has been reduced to $1/e^2$ of its peak value. The laser beam **169** passes through circular polarizer **163** and is then expanded by passing through beam expander **165**. The expanded laser beam then passes through beam shaping apparatus **167** to form a beam producing the elliptical footprint on a surface of the bent target segment **151, 403**. The beam shaping apparatus **167** may, for example, comprise one or more cylindrical lenses. However, it should be understood that any optical elements capable of shaping the beam emitted by laser **161** to produce an elliptical footprint on the bent target segment **151, 403** may be used.

[0052] The elliptical footprint can include a major axis that is substantially longer than a minor axis. In some embodiments, for example, major axis is at least about ten times longer than minor axis. However, the length and width of the elongated radiation zone are dependent upon the desired severing speed, desired initial crack size, thickness of the glass ribbon, laser power, etc., and the length and width of the radiation zone may be varied as needed.

[0053] As further shown in **FIG. 1**, the example glass cutting device **153** can also include a coolant fluid delivery apparatus **159** configured to cool the heated portion of the upwardly facing surface of the bent target segment **151**. The coolant fluid delivery apparatus **159** can comprise a coolant nozzle **177**, a coolant source **179** and an associated conduit **181** that may convey coolant to the coolant nozzle **177**.

[0054] With reference to **FIG. 3**, the coolant nozzle **177** can be configured to deliver a coolant jet **317** of coolant fluid to the upwardly facing surface **313, 405** of the bent target segment **151, 403**. The coolant nozzle **177** can have various internal diameters to form a cooling zone **319** of a desired size. As with elongated radiation zone **227**, the diameter of coolant nozzle **177**, and the subsequent diameter of coolant jet **317**, may be varied as needed for the particular process conditions. In some embodiments, the area of the glass ribbon immediately impinged upon by the coolant (cooling zone) can have a diameter shorter than the minor axis of the radiation zone **227**. However, in certain other embodiments, the

diameter of the cooling zone may be larger than the minor axis of elongated radiation zone 227 based on process conditions such as speed, glass thickness, laser power, etc. Indeed, the (cross sectional) shape of the coolant jet may be other than circular, and may, for example, have a fan shape such that the cooling zone forms a line rather than a circular spot on the surface of the glass ribbon. A line-shaped cooling zone may be oriented, for example, perpendicular to the major axis of elongated radiation zone 227. Other shapes may be beneficial.

[0055] In one example, the coolant jet 317 comprises water, but may be any suitable cooling fluid (e.g., liquid jet, gas jet or a combination thereof) that does not stain or damage the upwardly facing surface 313, 405 of the bent target segment 151, 403 of the glass ribbon 103. The coolant jet 317 can be delivered to a surface of the glass ribbon 103 to form the cooling zone 319. As shown, the cooling zone 319 can trail behind the elongated radiation zone 227 to propagate an initial crack formed by aspects of the disclosure described more fully below.

[0056] The combination of heating and cooling with the laser apparatus 155 and the cooling apparatus 159 can effectively sever the edge portions 201, 203 from the central portion 205 while minimizing or eliminating undesired residual stress, microcracks or other irregularities in the opposed edges 223, 225 of the central portion 205 that may be formed by other severing techniques. Moreover, due to the bent orientation of the bent target segment 151 within the cutting zone 147, the glass ribbon 103 can be properly positioned and stabilized to facilitate precise severing of the opposed edges 223, 225 during the severing process. Still further, due to the convex surface topography of the upwardly facing convex support surface 315 the edge portions (e.g., see 201 in broken lines in FIG. 3) can immediately travel away from the central portion 205, thereby reducing the probability that the edge portions will subsequently engage (and therefore damage) the pristine faces 139, 141 and/or the high quality opposed edges 223, 225 of the central portion 205.

[0057] Turning back to FIG. 1, the apparatus 101 may include structures configured to further process the severed edge portions 201, 203 and/or the central portion 205 of the glass ribbon 103 downstream from the cutting zone 147. For example, one or more glass

ribbon choppers **183** may be provided to chop, shred, break or otherwise compact the segments for disposal or recycling.

[0058] The central portion **205** of the glass ribbon **103** can be further processed by cutting into glass sheets for incorporation into optical components. For example, the apparatus **101** may include another severing device (not shown) configured to sever the central portion **205** of the glass ribbon **103** along the axis **217** transverse to the travel direction **213** of the glass ribbon **103**. Alternatively, as shown in **FIG. 1**, the central portion **139** of the glass ribbon **103** can be coiled into a coiled spool **185** for later processing. As shown, removing the edge portions **201**, **203** consequently removes the corresponding beads **207**, **209**. Removing the beads reduces the minimum bend radius to allow the central portion **205** of the glass ribbon **103** to be more efficiently wound into a coiled spool **185**. As schematically represented in **FIG. 1**, the wasted central core **187** of the coiled spool **185** is significantly reduced when compared to the wasted central core **189** of the coiled spool **124**. As such, the diameter " D_2 " of the coiled spool **185** of the central portion **205** is significantly smaller than the diameter " D_1 " of the required to store the same length of pre-processed glass ribbon in the coiled spool **124**.

[0059] Still further shown in **FIG. 1**, the apparatus **101** may also include further noncontact support members to guide at least the central portion **205** of the glass ribbon **103** downstream from the cutting zone **147**. For example, as shown, the apparatus can include a first air bar **188** and a second air bar **190** to guide the central portion **205** the glass ribbon for final processing without contacting the surfaces. Two support members are illustrated although a single support member or more than two support members may be provided in further examples. As further shown, an optional support member **191** can also be provided to allow the edge portion to be guided to the glass ribbon chopper. The optional support member **191** can optionally comprise an air bar or low friction surface to reduce binding and/or restricted movement as the edge portion proceeds to the glass ribbon choppers **183**.

[0060] Methods of fabricating a glass ribbon with the apparatus **101** will now be described. As shown in **FIG. 1**, the method can include the step of traversing the glass ribbon **103** in a downward direction **121** relative to the source **105** through the downward zone **123**. As shown, the glass ribbon **103** can travel substantially vertically in the downward

direction **121** although the downward direction may be angled in further examples wherein the glass ribbon **103** can travel at an inclined orientation in the downward direction.

[0061] The method can further include the step of bending the glass ribbon **103** in the bending zone **125** downstream from the downward zone **123**, wherein the glass ribbon **103** includes the upwardly concave surface **127** through the bending zone **125**. As shown, the lower portion **137** can be significantly lower than the bent target segment **151** in the cutting zone **147** although the lower portion **137** may be at substantially the same elevation or even higher than the bent target segment in further examples. Providing the lower portion **137** at a significantly lower position, as shown, can develop a predetermined amount of accumulated glass ribbon prior to engaging the support members (e.g., support member **135**) of the apparatus **101**. As such, vibrations or other disturbances upstream from the lower portion **137** may be absorbed by the accumulated glass ribbon within the bending zone. Moreover, the glass ribbon **103** may be drawn at a substantially constant or desired predetermined rate as it passes through the cutting zone **147** independent of how fast the glass ribbon **103** is being fed into the downward zone **123** by the source **105**. As such, providing an accumulation within the bending zone **125** can allow for further stabilization of the glass ribbon **103** within the cutting zone **147** while also allowing the glass ribbon **103** to be passed through the cutting zone **147** at a substantially constant or predetermined rate.

[0062] If provided, various techniques may be used to help maintain a desired accumulation of glass ribbon **103** within the bending zone **125**. For example, a proximity sensor **129** or other device may be able to sense a position of the accumulated ribbon to adjust the rate at which glass ribbon is fed into the downward zone **123** by the source **105** to provide the appropriate accumulation of glass ribbon **103**.

[0063] In further examples, the method can further include the step of bending the glass ribbon **103** downstream from the bending zone **125** to redirect the glass ribbon to travel in the travel direction **213**. As shown, the bending support member **135** may comprise a bent air bar designed to effect the desired change of direction without contacting the central portion **205** of the glass ribbon **103**. Furthermore, the method can also include the optional step of orienting the glass ribbon **103** being bent with the bending support member with the

lateral guides **143**, **145** to help orient the glass ribbon **103** in the correct lateral position relative to the travel direction **213** of the glass ribbon **103**.

[0064] The method can also include the step of traversing the glass ribbon **103** into the cutting zone **147** downstream from the bending zone **125** and then bending the glass ribbon **103** in the cutting zone **147** to provide the bent target segment **151**, **403** with a bent orientation in the cutting zone **147**.

[0065] As shown in **FIG. 1**, the glass ribbon **103** can be bent such that the bent orientation of the target segment **151** includes the upwardly facing convex surface **313**. In one example, the method can include the step of supporting the bent target segment **151** with the cutting support member **149** comprising the illustrated curved air bar. As shown, the cutting support member **149** can include an upwardly facing convex support surface **315** configured to bend the target segment **151** to establish the upwardly facing convex surface **313**.

[0066] As shown in **FIG. 4**, the glass ribbon **103** can alternatively be bent such that the bent orientation of the target segment **403** includes the upwardly facing concave surface **405**. In one example, the method can include the step of supporting the bent target area **403** with the cutting support member **401** comprising the illustrated curved air bar. As shown, the cutting support member **401** can include an upwardly facing concave support surface **407** configured to bend the target segment **403** to establish the upwardly facing concave surface **405**.

[0067] As shown in **FIG. 1**, the method can further include the step of severing at least one of the edge portions **201**, **203** from the central portion **205** of the bent target segment **151**, **403** within the cutting zone **147**. As shown in **FIG. 2**, the examples of the disclosure can include severing both of the edge portions **201**, **203** from the central portion **205** although a single edge portion may be severed from the central portion in further examples. Moreover, as shown in **FIG. 2**, both of the edge portions **201**, **203** are severed simultaneously from the central portion **205** although one of the edge portions may be severed before the other edge portion in further examples.

[0068] The step of severing can incorporate a wide range of techniques. For example, the edge portions **201**, **203** can be severed from the central portion **205** by way of

the glass cutting device **153** that can include the illustrated optical delivery apparatus **155** and the coolant fluid delivery apparatus **159**.

[0069] One example of initiating the severing process is illustrated in **FIGS. 5-7**. As shown in **FIG. 5**, a scribe **503** or other mechanical device can create an initial crack **501** with the point of the scribe to create a controlled surface defect at the site where the glass ribbon is to be severed. As shown, the scribe **503** includes a tip although an edge blade or other scribe technique may be used in further examples. Still further, the initial crack **501** or other surface imperfection may be formed by etching, laser impact, or other techniques.

[0070] As further illustrated in **FIG. 5**, the initial crack **501** or surface imperfection can be initially formed adjacent a leading edge **505** of the glass ribbon **103** traversing in the travel direction **213**. As shown in **FIG. 6**, the elongated radiation zone **227** may be formed on the upwardly facing convex or concave surface **313**, **405**. As the elongated radiation zone **227** is elongated in the travel direction **213**, the initial crack **501** can propagate into an elongated crack portion **601** extending partially through the thickness " T_2 " of the glass ribbon **103**. As shown in **FIG. 7**, the coolant jet **317** then contacts the cooling zone **319** to further propagate the elongated crack portion **601** completely through the thickness " T_2 " of the glass ribbon **103** to sever the corresponding edge portions **201**, **203** from the central portion **205** as indicated by reference number **701** in **FIG. 7**.

[0071] As shown in **FIG. 3**, the severed the opposed edge portions **201**, **203** can be effectively removed while leaving the central portion **205** with high quality opposed edges **229**, **231** with reduced internal stress profiles, reduced cracks, or other imperfections in the opposed edges **229**, **231**. As such, the central portion **205** can be bent, such as wound in the coiled spool **185** without cracking that may otherwise occur with reduced quality edges. Moreover, the higher quality edges can avoid scratching the central portion **205** during coiling that might otherwise occur with edge portions including glass shards or other imperfections.

[0072] The method can further include the step of supporting the bent target segment **151**, **403** with the upwardly facing convex or concave surface **315**, **407** of the cutting support member **149**, **401**. For instance, the bent target segment **151**, **403** can be supported by the convex or concave surface **315**, **407** of the illustrated air bar while severing the edge portions

201, 203 form the central portion **205** of the bent target segment **151, 403** within the cutting zone **147**.

[0073] The method can still further include the step of coiling the central portion **205** of the glass ribbon **103** into the coiled spool **185** after the step of severing. As such, the high quality central portion **205** of the glass ribbon may be efficiently coiled into a coiled spool **185** for subsequent shipping or processing into glass sheets.

[0074] **FIG. 8** illustrates an alternative apparatus **801** configured to sever at least one of the opposed edge portions **201, 203** from the central portion **205** of the glass ribbon **103**. As shown, the glass ribbon **103** can be cut in the bending zone **125** while the central portion **205** may thereafter be guided, for example, by way of support members **803, 807**. As illustrated, the support members **803, 807** can comprise noncontact support members, such as the illustrated air bars, configured to support the central portion **205** of the glass ribbon without contacting the pristine optical surfaces of the central portion **205**. The central portion **205** of the glass ribbon **103** can then be guided for coiling into the coiled spool **185**. Optional lateral guides **805** can be provided to help laterally orient the central portion **205** of the glass ribbon to prevent the glass ribbon **103** from floating off the support surface of the corresponding support members **803, 807**.

[0075] Methods of fabricating the glass ribbon with the apparatus **801** shown in **FIG. 8** will not be described. The method can include the step of traversing the glass ribbon **103** in the downward direction **121** relative to the source **105** through the downward zone **123**. The method can further include the step of bending the glass ribbon in the bending zone **125** downstream from the downward zone **123**. Once bent, the glass ribbon **103** include the upwardly concave surface **127** through the bending zone **125**. The method further includes the step of severing at least one of the edge portions **201, 203** from the central portion **205** of a target segment **809** within the bending zone **125**.

[0076] As shown, severing can occur within the bending zone **125** without necessarily supporting the target segment **809** with a support structure. Rather, gravity works to draw the edge portions **201, 203** away from the central portion **205**. Therefore, once severed, the edge portions **201, 203** can naturally move away from the central portion **205** under the influence of gravity. As such, there is a reduced probability of the severed edge

portions **201**, **203** achieving inadvertent contact with the pristine surface of the central portion **205**.

[0077] As shown, the step of severing shown in **FIG. 8** can be conducted with the glass cutting device **153** although other cutting devices may be incorporated in further examples. As further shown in **FIG. 8**, once severing is complete, the method can also include the optional steps of guiding the central portion **205**, for example, with support members **803**, **807** and coiling the central portion **205** into the coiled spool **185**.

[0078] It will be apparent to those skilled in the art that various modifications and variations can be made without departing from the spirit and scope of the claimed invention.