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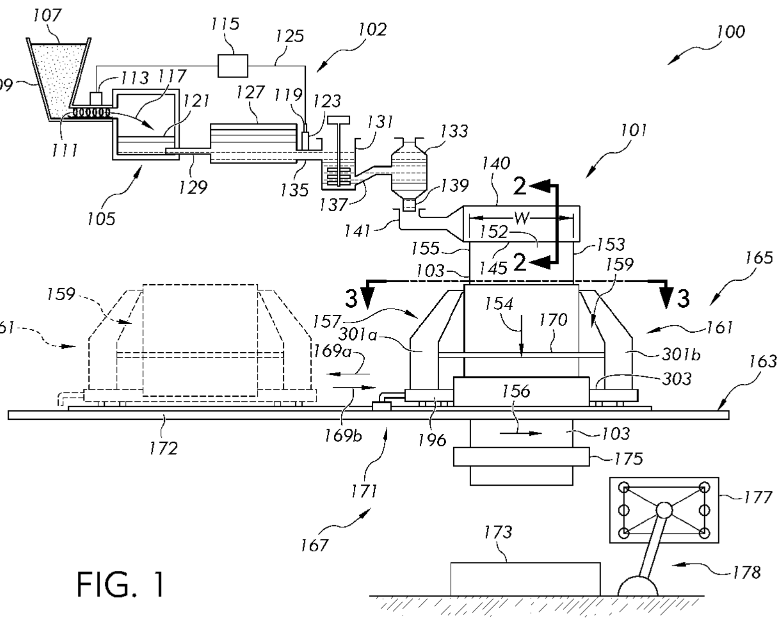

FIG. 1

(57) **Abstract:** In some embodiments, apparatus and methods for forming a glass ribbon can comprise a support member to move a draw stack along a support surface. In some embodiments, a housing can define an exterior area positioned outside of the wall of the draw stack and between the downstream portion of the draw stack and the housing. The housing can comprise a vent configured to regulate gas flow through the vent from the exterior area to a location outside of the housing and outside of the draw stack. In some embodiments, the draw stack can comprise fist gate and a second gate. Each gate can be provided with a corresponding row of conduits to cool a central edge plate.

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APPARATUS FOR FORMING A GLASS RIBBON

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application No. 63/135,029, filed on January 8, 2021, the content of which is relied upon and incorporated herein by reference in its entirety.

FIELD

[0002] The present disclosure relates generally to apparatus for forming glass and, more particularly, to apparatus for forming glass ribbon.

BACKGROUND

[0003] Early foldable smartphones and other electronic devices included a display incorporating a plastic substrate. Plastic substrates are capable of being repeatedly bended or folded without experiencing elastic deformation, but have a surface that is easily scratched or otherwise damaged, giving an exposed surface of the plastic substrates an unsightly appearance. Further, plastic substrates are known to have a relatively-high coefficient of thermal expansion ("CTE"), requiring thick plastic substrates that have enough strength to withstand the repeated bending and folding. However, thick plastic substrates increase the overall electronic device thickness, and can interfere with the sensitivity of the display.

[0004] A glass ribbon, on the other hand, has more-recently been used in the construction of displays for foldable/bendable electronic devices. A glass ribbon has a relatively low CTE compared to plastic, and can thus form a display substrate that is thinner than plastic, while still achieving comparable attributes. Further, glass ribbons can be more-resistant to scratching and other such damage, and sleeker in appearance. However, the attributes and structure of glass ribbons are sensitive to fluctuations in manufacturing parameters such as temperature, for example, that must be maintained within a small tolerance of a target value. To maintain such manufacturing parameters, the apparatus for manufacturing glass ribbons require regular maintenance, with limited downtime.

SUMMARY

[0005] Some example embodiments of the disclosure are described below with the understanding that any of the embodiments may be used alone or in combination with one another.

[0006] In some embodiments, an apparatus for forming a glass ribbon can comprise a draw stack comprising a wall circumscribing an interior area comprising an inlet, and an outlet located downstream from the inlet. The draw stack can further comprise at least one pull stage within the interior area. Each pull stage of the at least one pull stage can comprise a first pair of rollers configured to grip a first outer edge of the glass ribbon and a second pair of pull rollers configured to grip a second outer edge of the glass ribbon. The apparatus can further comprise a support member movable from a retracted position to an extended position to increase an elevation of the draw stack. The support member can be movable between the extended position to the retracted position to reduce the elevation of the draw stack. The support member can comprise an end portion.

[0007] In some embodiments, the apparatus can further comprise a track receiving the end portion of the support member to define a lateral travel path of the draw stack.

[0008] In some embodiments, the end portion comprises a wheel.

[0009] In some embodiments, the end portion comprises an air bearing.

[0010] In some embodiments, the apparatus can further comprise a lateral lock comprising a protrusion and a recess configured to receive the protrusion.

[0011] In some embodiments, a method can comprise moving a glass ribbon in a downward direction through an interior area of a draw stack while the draw stack is supported on a support surface and while an inlet of the interior area of the draw stack is aligned to receive the glass ribbon. The method can further comprise moving the draw stack in a horizontal direction relative to the support surface such that the inlet of the interior area is not aligned to receive the glass ribbon.

[0012] In some embodiments, after moving the draw stack, the method can comprise continuing to move the glass ribbon in the vertically downward direction without passing through the interior area of the draw stack.

[0013] In some embodiments, the horizontal direction can be defined by a track mounted relative to the support surface.

[0014] In some embodiments, the draw stack can be levitated on a cushion of gas while moving the draw stack in the horizontal direction.

[0015] In some embodiments, the method can further comprise lifting the draw stack in a vertically upward direction prior to moving the draw stack in the horizontal direction.

[0016] In some embodiments, the lifting the draw stack unlocks the draw stack to permit movement of the draw stack in the horizontal direction.

[0017] In some embodiments, prior to the moving the draw stack in the horizontal direction, the method can further comprise unlocking the draw stack to permit movement of the draw stack in the horizontal direction.

[0018] In some embodiments, an apparatus for forming a glass ribbon can comprise a draw stack comprising a wall circumscribing an interior area comprising an inlet and an outlet located downstream from the inlet. The draw stack can further comprise at least one pull stage within the interior area. Each pull stage of the at least one pull stage can comprise a first pair of rollers configured to grip a first outer edge of the glass ribbon and a second pair of pull rollers configured to grip a second outer edge of the glass ribbon. The apparatus can further comprise a housing circumscribing a downstream portion of the draw stack and the outlet of the interior area. The housing can define an exterior area positioned outside of the wall of the draw stack and between the downstream portion of the draw stack and the housing. The housing can comprise a vent configured to regulate gas flow through the vent from the exterior area to a location outside of the housing and outside of the draw stack.

[0019] In some embodiments, the vent can be adjustable to adjust a gas flow through the vent.

[0020] In some embodiments, the apparatus can further comprise a baffle configured to direct a first quantity of an input gas flow through the outlet and into the interior area and a second quantity of the input gas flow into the exterior area.

[0021] In some embodiments, methods of regulating an input gas flow can comprise directing a first quantity of the input gas flow through the outlet and into the interior area. The method can further comprise flowing the first quantity of the input gas flow through the interior area of the draw stack in a direction from the outlet towards the inlet. The method can further comprise directing a second quantity of the input gas flow into the exterior area. The method can further comprise flowing the second quantity of the input gas flow through the vent from the exterior area.

[0022] In some embodiments, the method can further comprise adjusting the vent to adjust the flow rate of the second quantity of the input gas flow through the vent.

[0023] In some embodiments, the method can further comprise cooling the downstream portion of the draw stack by transferring heat from the downstream portion of the draw stack to the second quantity of the input gas flow flowing through the exterior area.

[0024] In some embodiments, a baffle can direct the first quantity of the input gas through the outlet and further direct the second quantity of the input gas flow into the exterior area.

[0025] In some embodiments, a draw stack for forming a glass ribbon can comprise a wall circumscribing an interior area comprising an inlet, and an outlet located downstream from the inlet. The apparatus can further comprise at least one pull stage within the interior area. Each pull stage of the at least one pull stage can comprise a first pair of rollers configured to grip a first outer edge of the glass ribbon and a second pair of pull rollers configured to grip a second outer edge of the glass ribbon. The apparatus can further comprise a first gate mounted relative to the wall for movement in a first extension direction relative to the wall. The first gate can comprise a first end edge comprising an outer surface of a first central edge plate laterally disposed between a first lateral edge and a second lateral edge. The outer surface of the first central edge plate can protrude in the first extension direction from the first lateral edge by a first distance. The outer surface of the first central edge plate can protrude in the first extension direction from the second lateral edge by a second distance. The first gate can further comprise a first row of conduits disposed within an interior chamber of the first gate. An outlet of each conduit of the first row of conduits can face an inner surface of the first central edge plate. The apparatus can further comprise a second gate mounted relative to the wall for movement in a second extension direction relative to the wall. The second gate can comprise a second end edge comprising an outer surface of a second central edge plate laterally disposed between a third lateral edge and a fourth lateral edge. The outer surface of the second central edge plate can protrude in the second extension direction from the third lateral edge by a third distance. The outer surface of the second central edge plate can protrude in the second extension direction from the fourth lateral edge by a fourth distance. The second gate can further comprise a second row of conduits disposed within an interior chamber of the second gate. An outlet of each conduit of the second row of conduits can face an inner surface of the second central edge plate. A width of the inlet can be defined between the outer surface of the first central edge plate and the outer surface of the second central edge plate.

[0026] In some embodiments, a distance in the first extension direction between the first lateral edge and the third lateral edge can be from about two times the width of the inlet to about ten times the width of the inlet.

[0027] In some embodiments, a distance in the first extension direction between the second lateral edge and the fourth lateral edge can be from about two times the width of the inlet to about ten times the width of the inlet.

[0028] In some embodiments, methods of regulating a temperature of a glass ribbon with the draw stack can comprise cooling a first outer edge of the glass ribbon by radiating heat through a first lateral space between the first lateral edge and the third lateral edge. The method can further comprise cooling a second outer edge of the glass ribbon by radiating heat through a second lateral space between the second lateral edge and the fourth lateral edge.

[0029] In some embodiments, the glass ribbon can travel within the interior area in a travel direction from the inlet towards the outlet while the first outer edge and the second outer edge passes between the outer surface of the first central edge plate and the outer surface of the second central edge plate.

[0030] In some embodiments, the method can further comprise cooling a width of the glass ribbon positioned between the outer surface of the first central edge plate and the outer surface of the second central edge plate by radiating heat from the width of the glass ribbon to the first central edge plate and the second central edge plate.

[0031] In some embodiments, the methods can further comprise emitting gas from the outlet of at least one conduit of the first row of conduits to convect heat from the first central edge plate and emitting gas from the outlet of at least one conduit of the second row of conduits to convect heat from the second central edge plate.

[0032] In some embodiments, the method can comprise modifying a difference between flow rates of gas being admitted by at least two conduits of the first row of conduits to adjust a thickness profile across the width of the glass ribbon.

[0033] In some embodiments, the cooling the first outer edge can comprise radiating heat through the first lateral space to a first fluid cooled element and the cooling of the second outer edge comprises radiating heat through the second lateral space to a second fluid cooled element.

[0034] In some embodiments, the method can further comprise adjusting the width of the inlet such that a distance in the first extension direction between the first lateral edge and the third lateral edge is from about two times the width of the inlet to about ten times the width of the inlet.

[0035] In some embodiments, the method can comprise adjusting the width of the inlet provides a distance in the first extension direction between the second lateral edge and the fourth lateral that is from about two times the width of the inlet to about ten times the width of the inlet.

[0036] Additional embodiments disclosed herein will be set forth in the detailed description that follows. It is to be understood that both the foregoing general description and the following detailed description present embodiments intended to provide an overview or framework for understanding the nature and character of the embodiments disclosed herein. The accompanying drawings are included to provide further understanding, and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments of the disclosure, and together with the description explain the principles and operations thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

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

[0038] FIG. 1 schematically illustrates some exemplary embodiments of apparatus for forming a glass ribbon;

[0039] FIG. 2 illustrates a schematic cross-sectional view of a forming device of the apparatus taken along line 2-2 of **FIG. 1;**

[0040] FIG. 3 illustrates a schematic top view of the apparatus along line 3-3 of **FIG. 1**;

[0041] FIG. 4 illustrates a schematic sectional view of the apparatus along lines 4A-4A of **FIG. 3** with a draw stack of **FIGS. 1 and 3** locked from a vertical movement and a horizontal movement relative to a support surface;

[0042] FIG. 5 illustrates a schematic sectional view of the apparatus along lines 4A-4A of **FIG. 3** with the draw stack of **FIGS. 1 and 3** unlocked from a vertical movement while remaining locked from a horizontal movement relative to a support surface;

[0043] FIG. 6 illustrates a schematic sectional view of the apparatus along lines 4A-4A of **FIG. 3** with the draw stack of **FIGS. 1 and 3** with the draw stack being lifted in a vertically upward direction to horizontally unlock the draw stack;

[0044] FIG. 7 illustrates a schematic sectional view of the apparatus along lines 4A-4A of **FIG. 3** with the draw stack of **FIGS. 1 and 3** with the draw stack being lifted as in **FIG. 6** while also levitating the draw stack with a cushion of gas;

[0045] FIG. 8 illustrates a schematic sectional view of the draw stack along line 8-8 of **FIG. 3**;

[0046] FIG. 9 illustrates a schematic sectional view of the draw stack along line 9-9 of **FIG. 8**;

[0047] FIG. 10 illustrates a perspective view of a first gate and a second gate of the draw stack along line 10-10 of **FIG. 8**; and

[0048] FIG. 11 illustrates a perspective view of interior portions of the first gate and the second gate of **FIG. 10**.

DETAILED DESCRIPTION

[0049] Embodiments will now be described more fully hereinafter with reference to the accompanying drawings in which example embodiments are shown. Whenever possible, the same reference numerals are used throughout the drawings to refer to the same or like parts. However, this disclosure may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein.

[0050] The present disclosure relates to an apparatus for forming a glass ribbon (hereinafter a “glass forming apparatus”). In some embodiments, the glass forming apparatus can comprise a forming device for producing a glass ribbon from a quantity of molten glass-forming material. Throughout the application, “molten glass-forming material” is considered molten material that can be cooled into a glass material. Throughout the application, “molten glass-forming ribbon” is considered a molten ribbon of material that can be cooled into a glass ribbon in a cooled elastic state. Unless otherwise indicated, throughout the application, “glass ribbon” can be considered a molten glass-forming ribbon, a cooled glass ribbon in a cooled elastic state, or a ribbon of material that is transitioning from a molten glass-forming ribbon into a cooled glass ribbon in an elastic state. A wide variety of forming devices may be provided as part of the glass forming apparatus such as a fusion-down-draw device, a press-roll device, slot-draw device or other device configured to produce a glass ribbon from a quantity of molten glass-forming material.

[0051] As discussed above, the glass forming apparatus can comprise a forming device. Alternatively, or in addition, the glass forming apparatus can comprise a processing apparatus to process the glass ribbon produced by the forming device. Thus, for purposes of this application, the glass forming apparatus can comprise the processing apparatus alone or in combination with the forming device. In some embodiments, the processing apparatus can be decoupled from the forming device. For example, the processing apparatus can be adjustable relative to the forming device and/or a support surface between an aligned orientation and an orientation that is not aligned. In the aligned orientation, glass ribbon produced by the forming device can be received by an interior area of a draw stack of the processing apparatus to process the glass ribbon. Alternatively, the processing apparatus can be adjusted relative to the forming device and/or support surface to the orientation that is not aligned where the processing apparatus is rendered accessible for maintenance, repairs and alterations. When the processing apparatus is in not aligned, in some embodiments, glass ribbon still being produced by the forming device may not received by the processing apparatus but may be deposited in a cullet for disposal.

[0052] In some embodiments, the processing apparatus can comprise a draw stack comprising an upper transition region with a pair of adjustable gates. The adjustable gates can each be moved toward and/or away from a flow path along which the glass ribbon enters the draw stack to customize cooling of the glass ribbon. In some embodiments, the gates can be configured to provide cooling to the glass ribbon traveling between the gates. In further embodiments, the cooling along the end edge can vary along a length of the end edge to provide a desired cooling profile to modify the thickness profile along the width of the glass ribbon passing between the end edges of the adjustable gates. The pair of adjustable gates can also provide enlarged lateral spaces to allow radiative cooling of the outer edges of the glass ribbon.

[0053] In some embodiments, a housing may be provided to circumscribe a downstream portion of the draw stack and the outlet of the interior area. In some embodiments, a baffle may be provided to direct a first quantity of the input gas flow through the outlet of the interior area of the housing and direct a second quantity of the input gas flow into an exterior area. These embodiments can help control the cooling provided by input air flowing into the interior area of the draw stack and can also help cool an outer surface of the draw stack with the air flowing into the exterior area.

[0054] Methods and apparatus for manufacturing glass will now be described by way of exemplary embodiments for forming a glass ribbon from a quantity of molten glass-forming material. As schematically illustrated in **FIG. 1**, in some embodiments, an exemplary glass manufacturing apparatus **100** can include a glass melting and delivery apparatus **102** and a glass forming apparatus **101** including a forming device **140** designed to produce a glass ribbon **103** from a quantity of molten glass-forming material **121**. In some embodiments, the glass ribbon **103** can include a central portion **152** disposed between a first outer edge **153** and a second outer edge **155** opposite the first outer edge **153**. The first outer edge **153** and second outer edge **155** each extends in a travel direction **154** of the glass ribbon **103** and are separated by a width "**W**" that extends in a width direction **156** that is perpendicular to the travel direction **154**. The travel direction **154** can comprise a direction along which the glass ribbon **103** can be drawn from the forming device **140.**

[0055] In some embodiments, the glass melting and delivery apparatus **102** 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**. In some embodiments, an optional controller **115** can be operated to activate the motor **113** to introduce a desired amount of batch material **107** into the melting vessel **105**, as indicated by arrow **117**. The melting vessel **105** can heat the batch material **107** to provide molten glass-forming material **121**. In some embodiments, a melt probe **119** can be employed to measure a level of molten glass-forming material **121** within a standpipe **123** and communicate the measured information to the controller **115** by way of a communication line **125**.

[0056] Additionally, in some embodiments, the glass melting and delivery apparatus **102** can include a first conditioning station including 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 glass-forming material **121** can be gravity fed from the melting vessel **105** to the fining vessel **127** by way of the first connecting conduit **129**. For example, in some embodiments, gravity can drive the molten glass-forming material **121** through an interior pathway of the first connecting conduit **129** from the melting vessel **105** to the fining vessel **127**. Additionally, in some embodiments, bubbles can be removed from the molten glass-forming material **121** within the fining vessel **127** by various techniques.

[0057] In some embodiments, the glass melting and delivery apparatus **102** can further include a second conditioning station including a mixing chamber **131** that can be located downstream from the fining vessel **127**. The mixing chamber **131** can be employed to provide a homogenous composition of molten glass-forming material **121**, thereby reducing or eliminating inhomogeneity that may otherwise exist within the molten glass-forming material **121** exiting the fining vessel **127**. As shown, the fining vessel **127** can be coupled to the mixing chamber **131** by way of a second connecting conduit **135**. In some embodiments, molten glass-forming material **121** can be gravity fed from the fining vessel **127** to the mixing chamber **131** by way of the second connecting conduit **135**. For example, in some embodiments, gravity can drive the molten glass-forming material **121** through an interior pathway of the second connecting conduit **135** from the fining vessel **127** to the mixing chamber **131**.

[0058] Additionally, in some embodiments, the glass melting and delivery apparatus **102** can include a third conditioning station including a delivery vessel **133** that can be located downstream from the mixing chamber **131**. In some embodiments, the delivery vessel **133** can condition the molten glass-forming material **121** to be fed into an inlet conduit **141**. For example, the delivery vessel **133** can function as an accumulator and/or flow controller to adjust and provide a consistent flow of molten glass-forming material **121** to the inlet conduit **141**. As shown, the mixing chamber **131** can be coupled to the delivery vessel **133** by way of a third connecting conduit **137**. In some embodiments, molten glass-forming material **121** can be gravity fed from the mixing chamber **131** to the delivery vessel **133** by way of the third connecting conduit **137**. For example, in some embodiments, gravity can drive the molten glass-forming material **121** through an interior pathway of the third connecting conduit **137** from the mixing chamber **131** to the delivery vessel **133**. As further illustrated, in some embodiments, a delivery pipe **139** can be positioned to deliver molten glass-forming material **121** to glass forming apparatus **101**, for example the inlet conduit **141** of the forming device **140**.

[0059] The glass forming apparatus **101** can comprise various embodiments of the forming device **140** in accordance with features of the disclosure including, but not limited to a fusion forming device with a wedge for fusion drawing the glass ribbon, a forming device with a slot to slot draw the glass ribbon, or a forming device provided with press rolls to press roll the glass ribbon from the forming device. By way of illustration, the forming device **140** shown and disclosed herein can be provided to fusion draw the molten glass-forming material **121** off a bottom edge, defined as a root **145**, of a forming wedge **201** (see **FIG. 2**) to produce a ribbon of molten glass-forming material that can be drawn and cooled into the glass ribbon **103**. For example, in some embodiments, the molten glass-forming material **121** can be delivered from the inlet conduit **141** to the forming device **140**. The molten glass-forming material **121** can then be formed into the glass ribbon **103** based at least in part on the structure of the forming device **140**. For example, as shown, the molten glass-forming material **121** can be drawn as a ribbon of molten glass-forming material off the bottom edge (e.g., root **145)** of the forming device **140** along a glass ribbon travel path **204** extending in the travel direction **154**.

[0060] For purposes of this application, the glass ribbon travel path **204** is the path at least partially defined by the glass forming apparatus **101** (when in line with the glass forming apparatus described herein) wherein the glass ribbon travels through the glass ribbon travel path **204**. Thus, for example, the glass ribbon travel path **204** can comprise dimensions of the glass ribbon **103** traveling along and through the glass ribbon travel path **204**. In some embodiments, the first outer edge **153** of the glass ribbon **103** can be coincident with the corresponding first outer edge of the glass ribbon travel path **204**, and the second outer edge **155** of the glass ribbon **103** can be coincident with the corresponding second outer edge of the glass ribbon travel path **204**. The glass ribbon travel path **204** can comprise a width extending in a width direction that can comprise the width "**W**" of the glass ribbon **103** extending in the width direction **156** of the glass ribbon **103**. The width direction of the width of the glass ribbon travel path **204** can extend perpendicular to the travel direction **154** from the first outer edge of the glass ribbon travel path **204** to the second outer edge of the glass ribbon travel path **204**. In some embodiments, the width "**W**" of the glass ribbon **103** can be substantially equal to the width of the glass ribbon travel path **204**.

[0061] In some embodiments, the width "**W**" of the glass ribbon **103** can be greater than or equal to about 20 mm, such as greater than or equal to about 50 mm, such as greater than or equal to about 100 mm, such as greater than or equal to about 500 mm, such as greater than or equal to about 1000 mm, such as greater than or equal to about 2000 mm, such as greater than or equal to about 3000 mm, such as greater than or equal to about 4000 mm, although other widths less than or greater than the widths mentioned above can be provided in further embodiments. For example, in some embodiments, the width “**W**” of the glass ribbon **103** can be from about 20 mm to about 4000 mm, such as from about 50 mm to about 4000 mm, such as from about 100 mm to about 4000 mm, such as from about 500 mm to about 4000 mm, such as from about 1000 mm to about 4000 mm, such as from about 2000 mm to about 4000 mm, such as from about 3000 mm to about 4000 mm, such as from about 20 mm to about 3000 mm, such as from about 50 mm to about 3000 mm, such as from about 100 mm to about 3000 mm, such as from about 500 mm to about 3000 mm, such as from about 1000 mm to about 3000 mm, such as from about 2000 mm to about 3000 mm, such as from about 2000 mm to about 2500 mm, and all ranges and subranges therebetween.

[0062] As shown in **FIG. 2**, the forming device **140** can include a trough **203** oriented to receive the molten glass-forming material **121** from the inlet conduit **141**. For illustrative purposes, the molten glass-forming material **121** is shown in broken lines in **FIG. 2** for clarity. The forming device **140** can further include the forming wedge **201** including a pair of downwardly inclined converging surface portions **205, 207** extending between opposed ends of the forming wedge **201**. The pair of downwardly inclined converging surface portions **205**, **207** of the forming wedge **201** can converge along the travel direction **154** to intersect along the root **145** of the forming device **140**. A draw plane **209** of the glass manufacturing apparatus **100** can extend through the root **145** along the travel direction **154**. In some embodiments, the glass ribbon **103** can be drawn in the travel direction **154** along the draw plane **209**. As shown, the draw plane **209** can bisect the forming wedge **201** through the root **145** although, in some embodiments, the draw plane **209** can extend at other orientations relative to the root **145**.

[0063] The molten glass-forming material **121** can flow into and along the trough **203** of the forming device **140**. The molten glass-forming material **121** can then overflow from the trough **203** by simultaneously flowing over corresponding weirs **211, 213** and downward over the outer surfaces **215, 217** of the corresponding weirs **211, 213**. Respective streams of molten glass-forming material **121** can then flow along the downwardly inclined converging surface portions **205**, **207** of the forming wedge **201** to be drawn off the root **145** of the forming device **140**, where the flows converge and fuse into the ribbon of molten glass-forming material. The ribbon of molten glass-forming material can then be drawn off the root **145** in the draw plane **209** along the travel direction **154** and cooled into the glass ribbon **103**.

[0064] Referring once again to **FIG. 1**, the glass forming apparatus **101** can also include a glass processing apparatus **157**. When the glass processing apparatus **157** is aligned with the forming device **140**, the glass ribbon **103** formed with the forming device **140** can be processed by the glass processing apparatus **157**. In some embodiments, the glass processing apparatus **157** engages the first outer edge **153** and the second outer edge **155** of the glass ribbon **103** to draw the glass ribbon **103**, and accordingly, the molten glass-forming material **121** from the root **145** of the forming device **140**.

[0065] The glass ribbon **103** comprises a first major surface **219** and a second major surface **221** facing opposite directions and defining a thickness "**T**" (e.g., average thickness) at the central portion **152** of the glass ribbon **103**. In some embodiments, the thickness "**T**' of the glass ribbon **103** can be less than or equal to about 2 millimeters (mm), less than or equal to about 1 mm, less than or equal to about 0.5 mm, for example, less than or equal to about 300 micrometers (μm), less than or equal to about 200 μm, or less than or equal to about 100 μm, although other thicknesses may be provided in further embodiments. For example, in some embodiments, the thickness "**T**' of the glass ribbon **103** can be from about 50 μm to about 750 μm, from about 100 μm to about 700 μm, from about 200 μm to about 600 μm, from about 300 μm to about 500 μm, from about 50 μm to about 500 μm, from about 50 μm to about 700 μm, from about 50 μm to about 600 μm, from about 50 μm to about 500 μm, from about 50 μm to about 400 μm, from about 50 μm to about 300 μm, from about 50 μm to about 200 μm, from about 50 μm to about 100 μm, including all ranges and subranges of thicknesses therebetween. In addition, the glass ribbon **103** can include a variety of compositions including, but not limited to, soda-lime glass, borosilicate glass, alumino-borosilicate glass, alkali-containing glass, or alkali-free glass. Furthermore, the glass ribbon can comprise glass-ceramic in further embodiments.

[0066] As mentioned previously, the glass forming apparatus **101** can comprise the glass processing apparatus **157** alone or in combination with the forming device **140**. As shown in **FIGS. 1 and 3**, the glass processing apparatus **157** can comprise a draw stack **159**. As shown in **FIGS. 8 and 9**, the draw stack can comprise a wall **801** circumscribing an interior area **803** comprising an inlet **805**, and an outlet **807** located downstream from the inlet **805** in the travel direction **154**. The draw stack **159** can further comprise at least one pull stage **809, 811** within the interior area **803**, each pull stage of the at least one pull stage **809, 811** can comprise comprising a first pair of pull rollers **810a** (see **FIGS. 3 and 8**) configured to grip the first outer edge **153** of the glass ribbon **103** and a second pair of pull rollers **810b** (see **FIG. 3**) configured to grip the second outer edge **155** of the glass ribbon **103**. While **FIG. 8** illustrates the at least one pull stage **809, 811** comprising a first pull stage **809** and a second pull stage **811**, in further embodiments, the at least one pull stage may include a single pull stage or more than two pull stages.

[0067] As shown in **FIGS. 1 and 3**, a support apparatus **161** can be provided to support the draw stack **159** on a support surface **163**. In some embodiments, the support surface **163** can comprise the floor of an upper room **165** positioned above a lower room **167**. In some embodiments, the support apparatus **161** can be configured to movably support the draw stack **159** to move laterally in directions **169a, 169b** between a position wherein the draw stack **159** is aligned with the forming device **140** (as shown in solid lines in **FIG. 1**) to a position where the draw stack **159** is not aligned with the forming device **140** (as shown in broken lines in **FIG. 1**).

[0068] As shown in **FIG. 3**, in some embodiments, the support apparatus **161** can comprise support arms **301a, 301b, 301c, 301d**. As shown, an upper portion of each support arm that can be mounted, for example, to four upper corner portions of the draw stack **159**. As shown in **FIG. 1**, an optional platform **170** (not shown in **FIG. 3**) can be provided and mounted between two of the support arms to allow a user to access upper portions of the draw stack **159**. Furthermore, in some embodiments, the lower portion of each support arm can be mounted, for example, to a base **303**. While four support arms are shown, in further embodiments less than four support arms or more than four support arms may be provided. The support apparatus **161** can further comprise a support member comprising an end portion with a mobility device designed to reduce the effort to move the stack between the aligned position (shown in solid lines in **FIG. 1**) to the position out of alignment (shown in broken lines in **FIG. 1**). **FIGS. 4-7** show embodiments of a mobility device taken along lines **4A-4A** of **FIG. 3** where mobility devices taken at line **4B-4B** of **FIG. 3** may be identical or may not include a lateral lock as shown in **FIGS. 4-7**. In some embodiments, as shown, the mobility device can comprise a wheel **401** at an end portion **403** of a support member **405**. In some embodiments, four wheels may be provided at each section **4A-4A, 4B-4B** wherein the support apparatus **161** may permit the draw stack **159** to be pushed or pulled with reduced friction as the wheels **401** rotate. Other alternative rotating mobility devices may be provided such as cylindrical rollers, rotating spherical bearings. In further embodiments, nonrotating mobility devices may be provided. For example, rather than the wheels **401**, a self-lubricating material (e.g., Teflon) may be used to reduce the friction between the end portion of the support member and the support surface. In further embodiments, as shown, an end portion **407** of support member **409** may comprise an air bearing designed to produce a gas cushion **701** (see **FIG. 7**) to levitate the support apparatus **161** together with the draw stack **159**. In some embodiments, the wheels **401** can be provided as an alternative support member to the air bearing or in addition to the air bearing. If provided in addition, the mode of operation can be selected or the wheels **401** can be provided as a back-up to the air bearing.

[0069] In some embodiments, the support apparatus **161** may comprise a lateral lock **171** designed to inhibit motion in the horizontal directions **169a, 169b** in **FIG. 1**. Referring to **FIG. 4**, in some embodiments, the lateral lock **171** can comprise a protrusion **411** and a recess **413** configured to receive the protrusion **411**. The recess **413** can be provided as part of a bracket that can be fixedly mounted to the support surface **163**. As shown in **FIGS. 4-5** when the protrusion **411** is received in the recess **413**, the lateral lock **171** inhibits motion in the lateral directions. An optional latch device **415** that may include laterally moving latch members **417** may be provided to help prevent inadvertent removal of the protrusion **411** from the recess **413** in the locked orientation. As shown in **FIGS. 6-7**, the protrusion **411** can be removed from the recess **413** to unlock the support apparatus **161** and therefore permit lateral movement of the support apparatus **161** together with the draw stack **159** in horizontal directions **169a, 169b**.

[0070] Different embodiments of the lateral lock may be provided to allow the protrusion **411** to be selectively received by the recess **413** to laterally lock the support apparatus **161** or removed from the recess **413** to unlock the support apparatus **161** for movement in the horizontal direction **169a**. For example, the protrusion may be movable relative to the base **303**. For example, a crank may be provided to move the protrusion in and out of the recess **413** as desired. Alternatively, as shown in **FIGS. 6-7**, the entire base **303**, support arms **301a, 301b, 301c, 301d** and draw stack

159 may be lifted together with the protrusion **411** to lift the protrusion out of the recess **413**. In the illustrated embodiment, the support member **409** may be moved from a retracted position (see **FIGS. 4-5**) relative to the base **303** to an extended position (see **FIG. 6-7**) to increase an elevation of the draw stack **159** together with removing the protrusion **411** out of the recess **413** to laterally unlock the support apparatus **161**. The support member **409** can also be moved from the extended position (see **FIGS. 6-7**) to the retracted position (see **FIGS. 4-5**) to reduce the elevation of the draw stack **159** together with inserting the protrusion **411** within the recess **413** to laterally lock the support apparatus **161**.

[0071] In some embodiments, as shown in **FIGS. 3-7**, a track **305** may be provided to receive the end portions of the support member to define a lateral travel path **307** of the support apparatus **161** and draw stack **159**. The track **305** can provide accurate alignment when moving the draw stack **159** back into alignment with the forming device **140** as shown in **FIG. 1**. As shown, in some embodiments, the track **305** can comprise a channel with a lower plate **309** for bearing the load from the support member and side flanges **311a, 311b** for helping maintain proper alignment as the support apparatus **161** moves laterally. Furthermore, the channel arrangement can help trap air from exiting when forming the gas cushion **701** to provide a more stable air cushion that may not only levitate the end portion **407** but also self align the end portion **407** within the channel by way of the air cushion also forming along lateral portions of the end portion **407** between the lateral portions of the end portion and the side flanges **311a, 311b**.

[0072] Methods of processing glass ribbon will now be described with initial reference to **FIGS. 1 and 2**. A method can comprise forming glass ribbon **103** from one of the methods discussed above. For example, as shown in **FIG. 2**, the glass ribbon **103** may be drawn from the root **145** of the forming wedge **201**. As shown in **FIG. 1**, the draw stack **159** can be aligned with the forming wedge **201** such that the glass ribbon **103** travels along the glass ribbon travel path **204** and through the inlet **805** of the interior area **803** of the draw stack **159**. The first outer edge **153** of the glass ribbon **103** can be gripped between the first pair of pull rollers **810a** of the at least one pull stage **809, 811** and the second outer edge **155** of the glass ribbon **103** can be gripped between the second pair of pull rollers **810b** of the at least one pull stage **809, 811**. The glass ribbon can continue to be drawn with the at least one pull stages in the travel direction **154** that extends in a direction from the inlet **805** toward the outlet **807** of the draw stack **159**. Thus, the moving glass ribbon **103** can travel in a downward direction (e.g., in a direction of gravity) through the interior area **803** while the draw stack **159** is supported on the support surface **163** by way of the support apparatus **161**. The moving glass ribbon **103** can also travel in the downward direction through the interior area **803** while the inlet **805** of the interior area **803** is aligned with the forming device **140** to receive the glass ribbon **103** traveling along the glass ribbon travel path **204** from the forming device **140**. The glass ribbon can then travel through an opening **821** (see **FIG. 8**) in the partition **172** such that the glass ribbon travels into the lower room **167** (see **FIG. 1**) that may comprise a clean room to help inhibit such as prevent dust or other debris from contaminating the surfaces of the glass ribbon **103**. Once a sufficient length has been obtained, a glass separation apparatus **175** may separate the ribbon along the width "**W**" of the ribbon into a separated sheet of ribbon **177** that can be held and transported by a robot **178** to a storage container, conveyor other downstream processing station.

[0073] After a period of time, the draw stack **159** may need to be serviced. For example, heating elements, cooling elements, pull rollers or other components of the draw stack **159** may need to be serviced. In some embodiments, the draw stack **159** may be laterally moved in a horizontal direction **169a** (e.g., perpendicular or another angle relative to gravity) relative to the support surface **163** such that the inlet **805** of the interior area **803** of the draw stack **159** is out of alignment with the forming device **140** such that the glass ribbon travel path **204** does not travel through the inlet **805** of the draw stack **159**. Once out of alignment, the working components including the heating elements of the draw stack **159** can be powered down and the draw stack **159** can be serviced. While the draw stack **159** is out of alignment, glass ribbon **103** can continue to be fed in a vertically downward direction (e.g., the travel direction **154**) without passing through the interior area **803** of the draw stack **159**. Rather, the glass ribbon **103** can continue to be fed in the vertically downward direction into the opening **821** through the partition **172** (e.g., ceiling/floor) between the upper room **165** and the lower room **167** and into a cullet **173**. In such a manner, the production of glass ribbon by the forming device **140** can continue uninterrupted that can reduce down time and costs associated with shutting down the entire glass production line for servicing the draw stack.

[0074] In some embodiments, prior to the moving the draw stack **159** in the horizontal direction **169a**, the draw stack **159** can be horizontally unlocked. For instance, the lateral lock **171** can be engaged as shown in **FIGS. 1 and 4-5**. Then the protrusion **411** can be lifted out of the recess **413** to horizontally unlock the draw stack **159** to permit movement of the draw stack **159** in the horizontal direction **169a**. To lift the protrusion **411** out of the recess **413**, the protrusion may be moved vertically relative to the base **303**. Alternatively, as shown in **FIGS. 6-7**, the draw stack **159**, the base **303** and the protrusion **411** may be lifted together in a vertically upward direction **601a** to horizontally unlock the draw stack **159**. For example, an actuator **603** such as the illustrated hydraulic cylinder may be pressurized by a hydraulic source **606** to extend the piston **605** in direction **601b** relative to the base **303** to extend the support member **409** and thereby lift the draw stack **159**, the base **303** and the protrusion **411** together in the vertically upward direction **601a** to horizontally unlock the draw stack **159**. Once unlocked, the draw stack **159** can be moved in the horizontal direction **169a** to bring the draw stack **159** out of alignment to the service location indicated by broken lines in **FIG. 1**. In some embodiment, prior to lifting, the latch device **415**, if provided, may be unlatched to permit movement of the protrusion **411** out of the recess **413**.

[0075] In some embodiments, as shown in **FIG. 7**, a pressurized gas source **703** may be activated to produce the gas cushion **701** to levitate the draw stack **159** and support apparatus **161** while the draw stack **159** is lifted with the support member **409** in the extended position relative to the base **303**. The gas cushion **701** reduces the effort to move the support apparatus **161** together with the draw stack **159** in the horizontal direction **169a**. The wheel **401** can be provided in other embodiments as an alternative or in addition to the support member **409**. For example, as shown, the wheel **401** may be mounted by support member **405** to the base **303** wherein the wheel **401** is not configured to move vertically relative to the base **303**. Alternatively, although not shown, the wheel **401** may be extended to lift the draw stack **159**. In the illustrated embodiment, the wheel **401** can act as a backup mechanism to support the weight of the draw stack **159** when the support member **409** is retracted.

[0076] In some embodiments, the movement of the draw stack **159** in the direction **169a** can be limited to travel along lateral travel path **307** by the track **305**. For example, as shown, the end portion **407** of the support member **409** can be received within an interior area of the track defined by the lower plate **309** and side flanges **311a, 311b** to guide the draw stack **159** to travel in the direction **169a**. The draw stack **159** can then be serviced in the servicing position shown by broken lines in **FIG. 1**. Once complete, the draw stack **159** can then again be lifted by extending the support member **409** and the gas cushion **701** can be produced while the draw stack **159** is moved in the opposite direction **169b** until the protrusion **411** is aligned with the recess **413** of the lateral lock **171**. Once aligned with the recess **413**, the draw stack **159** is aligned with the forming device **140**. The pressurized gas source **703** can then be turned off or disengaged from the end portion **407** to eliminate the gas cushion **701**. The support member **409** can then be retracted to lower the draw stack into the aligned and working position where the draw stack again receives the glass ribbon through the inlet **805** of the interior area **803**. Once lowered, the protrusion **411** can be received in the recess **413** such that the lateral lock **171** laterally locks the draw stack **159** in the proper aligned orientation. In some embodiments, the latch device **415**, if provided, can be engaged to vertically lock the protrusion **411** within the recess **413**. The glass processing apparatus **157** can then be used to continue processing glass ribbon **103**.

[0077] To help process the glass ribbon **103**, the draw stack **159** can carefully control the temperature conditions of the glass ribbon being processed while passing through the interior area **803** of the draw stack **159**. As shown in **FIG. 8**, the glass ribbon can pass through a visco-elastic zone **813a** where the thickness of the glass ribbon **103** can be varied, the glass ribbon **103** can then travel in the travel direction **154** to the setting zone **813b** where the glass ribbon transitions from the visco-elastic state to the cooled elastic state. The glass ribbon **103** can then continue traveling in the travel direction **154** until the glass ribbon **103** has cooled to the elastic state in elastic zone **813c**. An interior air current **815** can travel upwardly due to the buoyancy of the gas since it is heated by the glass ribbon **103**. The interior air current **815** can be replenished by a first quantity **817** of input gas **819** entering into the interior area **803**. In some embodiments, the input gas **819** can pass upwardly through the opening **821** in the partition **172** between the upper room **165** and the lower room **167**. In some embodiments, the lower room **167** can comprise a clean room where the input gas **819** (e.g., input air) from the clean room is filtered to prevent contaminants (e.g., dust, debris) from being drawn into the draw stack **159** that may contaminate the pristine surface of the glass ribbon **103**.

[0078] In some embodiments, as shown in **FIGS. 8-9**, a housing **825** may be provided that circumscribes a downstream portion **828** of the draw stack **159** and the outlet **807** of the interior area **803**. The housing **825** can define an exterior area **827**

positioned outside of the wall **801** of the draw stack **159** and between the downstream portion **828** of the draw stack **159** and the housing **825**. The housing **825** can comprise a vent **829** configured to regulate gas flow through the vent from the exterior area **827** to a location **830** outside of the housing **825** and outside of the draw stack **159**. In some embodiments, the vent **829** can be adjustable to adjust a glass flow through the vent **829**. For example, as shown a slide closure **831** may be provided to adjust the size of the opening of the vent **829** and thereby control the flow rate of the gas traveling through the vent.

[0079] In some embodiments, a baffle **833** can be provided to direct the first quantity **817** of input gas **819** to flow through the outlet **807** of the interior area **803** of the draw stack **159** and then into the interior area **803** to flow upwardly toward the inlet **805** of the interior area **803** due to the buoyancy of the gas being heated by the glass ribbon **103**. The baffle **833** can also direct a second quantity **835** of the input gas **819** to flow into the exterior area **827**. In some embodiments, the baffle can comprise a first portion **837a** and second portion **837b** that diverge from one another in the upward direction and each act to divide the input gas **819** into the first quantity **817** and the second quantity **835** of gas. In some embodiments, as shown, the first portion **837a** and the second portion **837b** may be symmetrically disposed about the glass ribbon travel path **204**. A channel can be defined between corresponding lower portions of the first and second portions **837a, 837b** that can be laterally aligned with the outlet **807** of the interior area **803**. The upper portions can diverge to direct the second quantity **835** of the input gas **819** to the exterior area **827**.

[0080] Methods of regulating the input gas **819** can comprise directing the first quantity **817** of the input gas **819** to flow through the outlet **807** and into the interior area **803** of the draw stack **159**. The first quantity of the input gas **819** flowing within the interior area **803** can flow in the direction from the outlet **807** towards the inlet **805** of the interior area **803**. The method can further comprise directing the second quantity **835** of the input gas **819** into the exterior area **827**. The second quantity **835** of the input gas **819** can then flow through the vent **829** from the exterior area **827** to the location **830** outside of the exterior area **827**. As shown, the baffle **833** can divide the input gas **819** into the first quantity **817** of the input gas **819** directed pass through the outlet **807** and the second quantity **835** of input gas **819** flowing into the exterior area **827**. In some embodiments, the first and second portions **837a, 837b** can be adjustable relative to one another to adjust the proportions of the division of the input gas **819**. For example, the first and second portions **837a, 837b** can be moved laterally closer together to reduce the first quantity **817** of input gas **819** passing into the interior area **803** while increasing the second quantity **835** of input gas **819** passing into the exterior area **827**. In further examples, the first and second portions **837a, 837b** can be moved laterally farther away form one another to increase the first quantity **817** of the input gas **819** passing into the interior area **803** while decreasing the second quantity **835** of input gas **819** passing into the exterior area **827**. Adjusting the proportion of the input gas **819** passing as the first quantity **817** and the second quantity **835** can adjust the proportion of the input gas that cools the glass ribbon within the interior area **803**. In some embodiments, the downstream portion **828** of the draw stack **159** can be cooled by transferring heat from the downstream portion **828** of the draw stack **159** to the second quantity **835** of the input gas flow flowing through the exterior area **827**. The slide closures **831** of the vent **829** can also be adjusted to adjust the flow rate of the second quantity **835** of the input gas **819** flowing through the vent **829**. For example, adjusting the slide closures **831** to reduce the size of the vent **829** will reduce the second quantity **835** of the input gas flowing through the exterior area **827** and out the vent **829** while increasing the first quantity **817** of the input gas **819** passing into the interior area **803**. In another example, adjusting the slide closures **831** to increase the size of the vent **829** will increase the second quantity **835** of the input gas flowing through the exterior area **827** and out the vent **829** while decreasing the first quantity **817** of the input gas **819** passing into the interior area **803**. Maximum cooling of the ribbon with the input gas **819** can be achieved by maximizing the amount of input gas **819** flowing into the interior area **803**. Consequently, cooling of the glass ribbon **103** with the input gas **819** can be adjusted by a corresponding adjustment of the size of the vent **829** to proper size to achieve the optimal cooling with the input gas **819**. Furthermore, the downstream portion **828** of the draw stack **159** may be cooled by the second quantity **835** of the input gas **819** flowing through the exterior area **827**. Cooling of the downstream portion **828** of the draw stack **159** can enhance radiative heat transfer from the glass ribbon **103** to the downstream portion **828** of the draw stack **159**. However, convective cooling provided by the first quantity **817** of the input gas **819** can provide greater cooling of the glass ribbon **103** than the cooling of the glass ribbon provided by cooling the downstream portion **828** of the draw stack **159** with the second quantity **835** of the input gas **819**.

[0081] As shown in **FIG. 8**, the inlet **805** can be at least partially defined by a first gate **839a** and a second gate **839b**. In some embodiments, the first gate **839a** can be similar or identical to the second gate **839b**. Unless otherwise noted, features of one of the first gate and second gate described below can apply to the other of the first gate and the second gate.

[0082] The first gate **839a** can be mounted relative to the wall **801** for movement in a first extension direction **840a** relative to the wall **801**. As shown in **FIG. 11**, the first gate **839a** can comprise a first end edge **841a** comprising an outer surface **843a** of a first central edge plate **845a** laterally disposed between a first lateral edge **847a** and a second lateral edge **849a**. In some embodiments, the outer surface **843a** of the first central edge plate **845a** can protrude in the first extension direction **840a** from the first lateral edge **847a** by a first distance **851a**. In some embodiments, the outer surface **843a** of the first central edge plate **845a** can protrude in the first extension direction **840a** from the second lateral edge **849a** by a second distance **853a**. As shown, in some embodiments, the first distance **851a** can be substantially equal to the second distance **853a** although different distances may be provided in further embodiments. The first gate **839a** can further comprise a first row of conduits **855a** disposed within an interior chamber **857a** of the first gate **839a**. An outlet **859a** of each conduit of the first row of conduits **855a** can face and be spaced away from an inner surface **861a** of the first central edge plate **845a**.

[0083] The second gate **839b** can be mounted relative to the wall **801** for movement in a second extension direction **840b** relative to the wall **801**. The second gate **839b** can comprise a second end edge **841b** comprising an outer surface **843b** of a second central edge plate **845b** laterally disposed between a third lateral edge **847b** and a fourth lateral edge **849b**. In some embodiments, the outer surface **843b** of the second central edge plate **845b** can protrude in the second extension direction **840b** from the third lateral edge **847b** by a third distance **851b**. In further embodiments, the outer surface **843b** of the second central edge plate **845b** can protrude in the second extension direction **840b** from the fourth lateral edge **849b** by a fourth distance **853b**. The second gate **839b** can further comprise a second row of conduits **855b** disposed within the interior chamber **857b** of the second gate **839b**. An outlet **859b** of each conduit of the second row of conduits **855b** can face and be spaced away from an inner surface **861b** of the second central edge plate **845b**.

[0084] As shown in **FIG. 10**, a width **1001** of the inlet **805** can be defined between the outer surface **843a** of the first central edge plate **845a** and the outer surface **843b** of the second central edge plate **845b**. The width **1001** can be adjustable to control the rate that the first quantity **817** of the input gas **819** exits the inlet **805**. For example, the width **1001** of the inlet **805** can be reduced to reduce the rate that the first quantity **817** of the input gas **819** exits the inlet **805** by moving the first gate **839a** in the first extension direction **840a** and by moving the second gate **839b** in the second extension direction **840b** opposite the first extension direction **840a**. The first gate **839a** and the second gate **839b** can be moved in retraction directions (opposite the extension directions) to increase the width **1001** of the inlet **805** to increase the rate that the first quantity **817** of the input gas **819** exits the inlet **805**.

[0085] In some embodiments a distance **1003** in the first extension direction **840a** between the first lateral edge **847a** and the third lateral edge **847b** can be from about two times the width **1001** of the inlet **805** to about ten times the width **1001** of the inlet **805**, for example, from about two times the width **1001** of the inlet **805** to about five times the width **1001** of the inlet **805**. As shown in **FIG. 10**, the distance **1003** can comprise a width of a first lateral space **1007a** that can facilitate radiation of the edges of a glass ribbon **103** positioned between the outer surfaces **843a, 843b** of the central edge plates **845a, 845b**.

[0086] In further examples, a distance **1005** in the first extension direction **840a** between the second lateral edge **949a** and the fourth lateral edge can be from about two times the width **1001** of the inlet **805** to about ten times the width **1001** of the inlet **805**, for example, from about two times the width **1001** of the inlet **805** to about five times the width **1001** of the inlet **805**. As shown in **FIG. 10**, the distance **1005** can comprise a width of a second lateral space **1007b** that can facilitate radiation of the edges of a glass ribbon **103** positioned between the outer surfaces **843a, 843b** of the central edge plates **845a, 845b**.

[0087] Methods of cooling a glass ribbon **103** with the draw stack **159** will now be described. Glass ribbon **103** traveling in the travel direction **154** can pass through the inlet **805** of the stack. In some embodiments, the entire width of the glass ribbon **103** can be disposed within the width **1001** of the inlet **805** between the outer surfaces **843a, 843b** of the central edge plates **845a, 845b**. In some embodiments, the glass ribbon **103** travels within the interior area **803** in the travel direction **154** from the inlet **805** towards the outlet **807** while the first outer edge **153** and the second outer edge **155** of the glass ribbon **103** passes between the outer surface **843a** of the first central edge plate **845a** and the outer surface **843b** of the second central edge plate **845b**.

[0088] As the glass ribbon **103** is still in the visco-elastic zone **813a**, the width of the ribbon can be reduced by the pull rollers **810a**. To further influence the thickness of the glass ribbon **103** and/or cooling of the glass ribbon **103**, the method can comprise delivering gas from a source of gas (not shown), through the conduit and emitted from the outlet **859a** of at least one conduit of the first row of conduits **855a** to convect heat from the first central edge plate **845a** and emitting gas from the outlet **859b** of at least one conduit of the second row of conduits **855b** to convect heat from the second central edge plate **845b**. The central edge plates can act as radiative heat sinks for radiative heat transfer from the glass ribbon **103** to the central edge plates.

[0089] In some embodiments, the method can include cooling the width "**W**" of the glass ribbon **103** positioned between the outer surface **843a** of the first central edge plate **845a** and the outer surface **843b** of the second central edge plate **845b** by radiating heat from the width "**W**" of the glass ribbon **103** to the first central edge plate **845a** and the second central edge plate **845b**.

[0090] As shown in **FIG. 11**, in some embodiments, the conduits of the first gate **839a** can be uniformly spaced apart from one another by passing through corresponding apertures **1103a** of an alignment member **1101**. The empty apertures **1103b** can be used in the second gate **839b** to uniformly space the conduits while the apertures **1103a** in the alignment member **1101** of the second gate **839b** may be empty. As such, the first row of conduits **855a** can be staggered relative to the second row of conduits **855b** in the direction of the width of the glass ribbon **103** to allow more control of the thermal profile across the width of the glass ribbon **103**. Further thickness changes across the width of the glass ribbon **103** may be achieved by modifying the flow rates of the gas being admitted by one or more of the conduits of the first and/or second rows of conduits **855a, 855b**. For example, a difference between flow rates of gas being admitted by at least two conduits of the first row of conduits **855a** can be adjusted to adjust a thickness profile across the width of the glass ribbon. In addition or alternatively, a difference between flow rates of gas being admitted by at least two conduits of the second row of conduits **855b** can be adjusted to further adjust the thickness profile across the width of the glass ribbon.

[0091] In some embodiments, the methods can further comprise cooling the first outer edge **153** of the glass ribbon **103** by radiating heat through the first lateral space **1007a** between the first lateral edge **847a** and the third lateral edge **847b**. In further embodiments, the methods can comprise cooling the second outer edge **155** of the glass ribbon **103** by radiating heat through the second lateral space **1007b** between the second lateral edge **849a** and the fourth lateral edge **849b**. In some embodiments, methods can comprise adjusting the width **1001** of the inlet **805** such that the distance **1003** in the first extension direction **840a** between the first lateral edge **847a** and the third lateral edge **847b** is from about two times the width **1001** of the inlet **805** to about ten times (or about five times) the width **1001** of the inlet **805**. In further embodiments, methods can comprise adjusting the width **1001** of the inlet **805** such that the distance **1005** in the first extension direction **840a** between the second lateral edge **849a** and the fourth lateral edge **849b** is from about two times the width **1001** of the inlet **805** to about ten times (or about five times) the width **1001** of the inlet **805**.

[0092] The lateral spaces **1007a, 1007b** with the corresponding distances **1003, 1005** can provide space for radiative heat transfer from the outer edges **153, 155** that can facilitate cooling of the glass ribbon **103** passing through the inlet **805**. To further enhance radiative heat transfer, the method can cool the first outer edge **153** of the glass ribbon **103** by radiating heat through the first lateral space **1007a** to a first fluid cooled element **1011a** (shown schematically in broken lines). The method can further cool the second outer edge **155** of the glass ribbon **103** by radiating heat through the second lateral space **1007b** to a second fluid cooled element **1011b** (shown schematically in broken lines). The first and second fluid cooled elements **1011a, 1011b** are shown laterally spaced away from the corresponding lateral spaces **1007a, 1007b**. Although not shown, the fluid cooled elements may be located above or below the gates **839a, 839b**. Although not shown, the fluid cooled elements may be located at least partially within the lateral spaces **1007a, 1007b** or laterally within the lateral spaces **1007a, 1007b** while being disposed above or below the lateral spaces **1007a, 1007b**.

[0093] After passing through the inlet **805**, the glass ribbon **103** can optionally be further exposed to one or more other cooling elements **863** to help control the cooling of the glass ribbon **103** while the glass ribbon passes through the visco-elastic zone **813a**. The wall **801** within the setting zone **813b** and/or within the elastic zone

813c may include heating and/or cooling elements to further control cooling of the glass ribbon **103**.

[0094] In some embodiments, the disclosure provides a housing **825** and baffle **833** that can split an input gas **819** into a first quantity **817** of input gas and a second quantity **835** of input gas. The first quantity **817** of input gas may travel upwardly through the interior area **803** to help convective heat transfer cooling of the glass ribbon **103** traveling in the travel direction **154** within the interior area **803**. Adjusting the vents **829** can help adjust the proportion of first quantity **817** to the second quantity **835** of input gas **819** to help fine tune the extent that the glass ribbon **103** is cooled by the first quantity **817** passing upward through the interior area **803**. Furthermore, the width **1001** of the inlet **805** can be adjusted by the first and second gates **839a, 839b** to help control the rate that the first quantity **817** of input gas exits the interior area **803** to further control cooling of the glass ribbon **103** within the draw stack **159**. Still further, the gates **839a, 839b** can include conduits **855a, 855b** to allow thickness control of the glass ribbon **103** wherein a desired thickness profile can be provided by adjusting the gas flow rate through the conduits **855a, 855b**. Furthermore, the gates **839a, 839b** can be arranged with lateral spaces **1007a, 1007b** that can have larger widths than the width **1001** of the inlet **805** to facilitate radiative cooling of the outer edges **153, 155** of the glass ribbon **103**. Still further, the draw stack **159** can be supported by a support apparatus **161** to permit movement of the draw stack **159** to a service location for servicing the draw stack without the need to stop the glass production process as the draw stack **159** is out of alignment with the forming device **140** in the service location.

[0095] It should be understood that while various embodiments have been described in detail with respect to certain illustrative and specific examples thereof, the present disclosure should not be considered limited to such, as numerous modifications and combinations of the disclosed features are possible without departing from the scope of the following claims.

What is claimed is:

1. An apparatus for forming a glass ribbon comprising:

a draw stack comprising a wall circumscribing an interior area comprising an inlet, and an outlet located downstream from the inlet, the draw stack further comprising at least one pull stage within the interior area, each pull stage of the at least one pull stage comprising a first pair of rollers configured to grip a first outer edge of the glass ribbon and a second pair of pull rollers configured to grip a second outer edge of the glass ribbon; and

a support member movable from a retracted position to an extended position to increase an elevation of the draw stack, the support member movable between the extended position to the retracted position to reduce the elevation of the draw stack, the support member comprising an end portion.

2. The apparatus of claim 1, further comprising a track receiving the end portion of the support member to define a lateral travel path of the draw stack.

3. The apparatus of any one of claims 1-2, wherein the end portion comprises a wheel.

4. The apparatus of any one of claims 1-2, wherein the end portion comprises an air bearing.

5. The apparatus of any one of claims 1-4, further comprising a lateral lock comprising a protrusion and a recess configured to receive the protrusion.

6. A method comprising:

moving a glass ribbon in a downward direction through an interior area of a draw stack while the draw stack is supported on a support surface and while an inlet of the interior area of the draw stack is aligned to receive the glass ribbon; and

moving the draw stack in a horizontal direction relative to the support surface such that the inlet of the interior area is not aligned to receive the glass ribbon.

7. The method of claim 6, wherein, after moving the draw stack, the method comprises continuing to move the glass ribbon in the vertically downward direction without passing through the interior area of the draw stack.

8. The method of any one of claims 6-7, wherein the horizontal direction is defined by a track mounted relative to the support surface.

9. The method of any one of claims 6-8, wherein the draw stack is levitated on a cushion of gas while moving the draw stack in the horizontal direction.

10. The method of any one of claims 6-9, further comprising lifting the draw stack in a vertically upward direction prior to moving the draw stack in the horizontal direction.

11. The method of claim 10, wherein the lifting the draw stack unlocks the draw stack to permit movement of the draw stack in the horizontal direction.

12. The method of any one of claims 6-9, wherein prior to the moving the draw stack in the horizontal direction, the method further comprises unlocking the draw stack to permit movement of the draw stack in the horizontal direction.

13. An apparatus for forming a glass ribbon comprising:

a draw stack comprising a wall circumscribing an interior area comprising an inlet and an outlet located downstream from the inlet, the draw stack further comprising at least one pull stage within the interior area, each pull stage of the at least one pull stage comprising a first pair of rollers configured to grip a first outer edge of the glass ribbon and a second pair of pull rollers configured to grip a second outer edge of the glass ribbon; and

a housing circumscribing a downstream portion of the draw stack and the outlet of the interior area, the housing defining an exterior area positioned outside of the wall of the draw stack and between the downstream portion of the draw stack and the housing, the housing comprising a vent configured to regulate gas flow through the vent from the exterior area to a location outside of the housing and outside of the draw stack.

14. The apparatus of claim 13, wherein the vent is adjustable to adjust a gas flow through the vent.

15. The apparatus of any one of claims 13-14, further comprising a baffle configured to direct a first quantity of an input gas flow through the outlet and into the interior area and a second quantity of the input gas flow into the exterior area.

16. A method of regulating an input gas flow with the apparatus of claim 13, the method comprising:

directing a first quantity of the input gas flow through the outlet and into the interior area;

flowing the first quantity of the input gas flow through the interior area of the draw stack in a direction from the outlet towards the inlet;

directing a second quantity of the input gas flow into the exterior area;

flowing the second quantity of the input gas flow through the vent from the exterior area.

17. The method of claim 16, further comprising adjusting the vent to adjust the flow rate of the second quantity of the input gas flow through the vent.

18. The method of any one of claims 16-17, further comprising cooling the downstream portion of the draw stack by transferring heat from the downstream portion of the draw stack to the second quantity of the input gas flow flowing through the exterior area.

19. The method of any one of claims 16-18, wherein a baffle directs the first quantity of the input gas through the outlet and further directs the second quantity of the input gas flow into the exterior area.

20. A draw stack for forming a glass ribbon comprising:

a wall circumscribing an interior area comprising an inlet, and an outlet located downstream from the inlet;

at least one pull stage within the interior area, each pull stage of the at least one pull stage comprising a first pair of rollers configured to grip a first outer edge of the glass ribbon and a second pair of pull rollers configured to grip a second outer edge of the glass ribbon;

a first gate mounted relative to the wall for movement in a first extension direction relative to the wall, the first gate comprising a first end edge comprising an outer surface of a first central edge plate laterally disposed between a first lateral edge and a second lateral edge, the outer surface of the first central edge plate protruding in the first extension direction from the first lateral edge by a first distance and the outer surface of the first central edge plate protruding in the first extension direction from the second lateral edge by a second distance, the first gate further comprising a first row of conduits disposed within an interior chamber of the first gate, an outlet of each conduit of the first row of conduits facing an inner surface of the first central edge plate; and

a second gate mounted relative to the wall for movement in a second extension direction relative to the wall, the second gate comprising a second end edge comprising an outer surface of a second central edge plate laterally disposed between a third lateral edge and a fourth lateral edge, the outer surface of the second central edge plate protruding in the second extension direction from the third lateral edge by a third distance and the outer surface of the second central edge plate protruding in the second extension direction from the fourth lateral edge by a fourth distance, the second gate further comprising a second row of conduits disposed within an interior chamber of the second gate, an outlet of each conduit of the second row of conduits facing an inner surface of the second central edge plate,

wherein a width of the inlet is defined between the outer surface of the first central edge plate and the outer surface of the second central edge plate.

21. The draw stack of claim 20, wherein a distance in the first extension direction between the first lateral edge and the third lateral edge is from about two times the width of the inlet to about ten times the width of the inlet.

22. The draw stack of any one of claims 20-21, wherein a distance in the first extension direction between the second lateral edge and the fourth lateral edge is from about two times the width of the inlet to about ten times the width of the inlet.

23. A method of regulating a temperature of a glass ribbon with the draw stack of claim 20, the method comprising:

cooling a first outer edge of the glass ribbon by radiating heat through a first lateral space between the first lateral edge and the third lateral edge; and

cooling a second outer edge of the glass ribbon by radiating heat through a second lateral space between the second lateral edge and the fourth lateral edge.

24. The method of claim 23, wherein the glass ribbon travels within the interior area in a travel direction from the inlet towards the outlet while the first outer edge and the second outer edge passes between the outer surface of the first central edge plate and the outer surface of the second central edge plate.

25. The method of any one of claims 23-24, further comprising cooling a width of the glass ribbon positioned between the outer surface of the first central edge plate and the outer surface of the second central edge plate by radiating heat from the width of the glass ribbon to the first central edge plate and the second central edge plate.

26. The method of claim 25, further comprising emitting gas from the outlet of at least one conduit of the first row of conduits to convect heat from the first central edge plate and emitting gas from the outlet of at least one conduit of the second row of conduits to convect heat from the second central edge plate.

27. The method of claim 26, comprising modifying a difference between flow rates of gas being admitted by at least two conduits of the first row of conduits to adjust a thickness profile across the width of the glass ribbon.

28. The method of any one of claims 23-27, wherein the cooling the first outer edge comprises radiating heat through the first lateral space to a first fluid cooled element and the cooling of the second outer edge comprises radiating heat through the second lateral space to a second fluid cooled element.

29. The method of cany one of claims 23-28, further comprising adjusting the width of the inlet such that a distance in the first extension direction between the first

lateral edge and the third lateral edge is from about two times the width of the inlet to about ten times the width of the inlet.

30. The method of claim 29, wherein the adjusting the width of the inlet provides a distance in the first extension direction between the second lateral edge and the fourth lateral that is from about two times the width of the inlet to about ten times the width of the inlet.

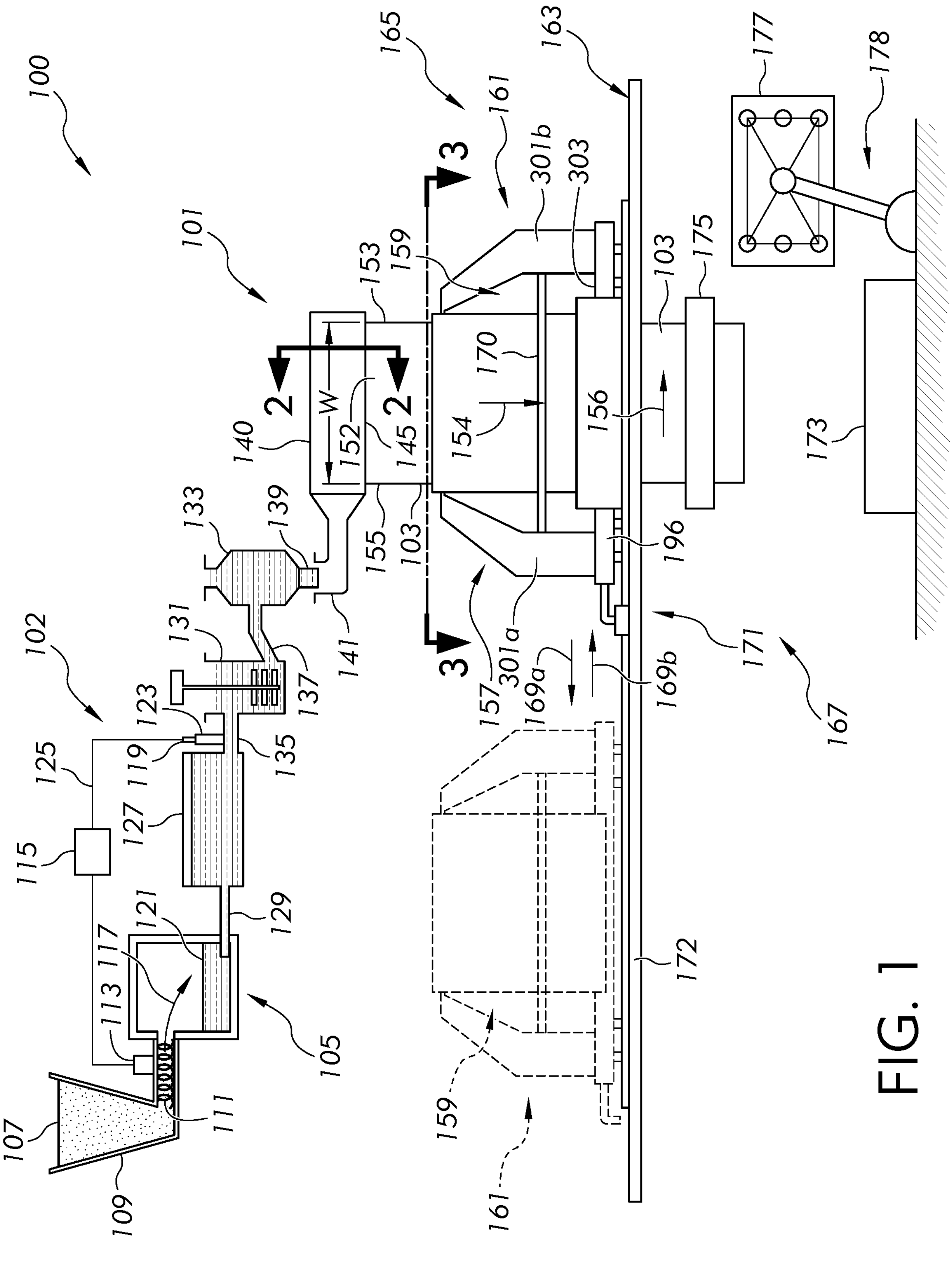
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FIG. 1

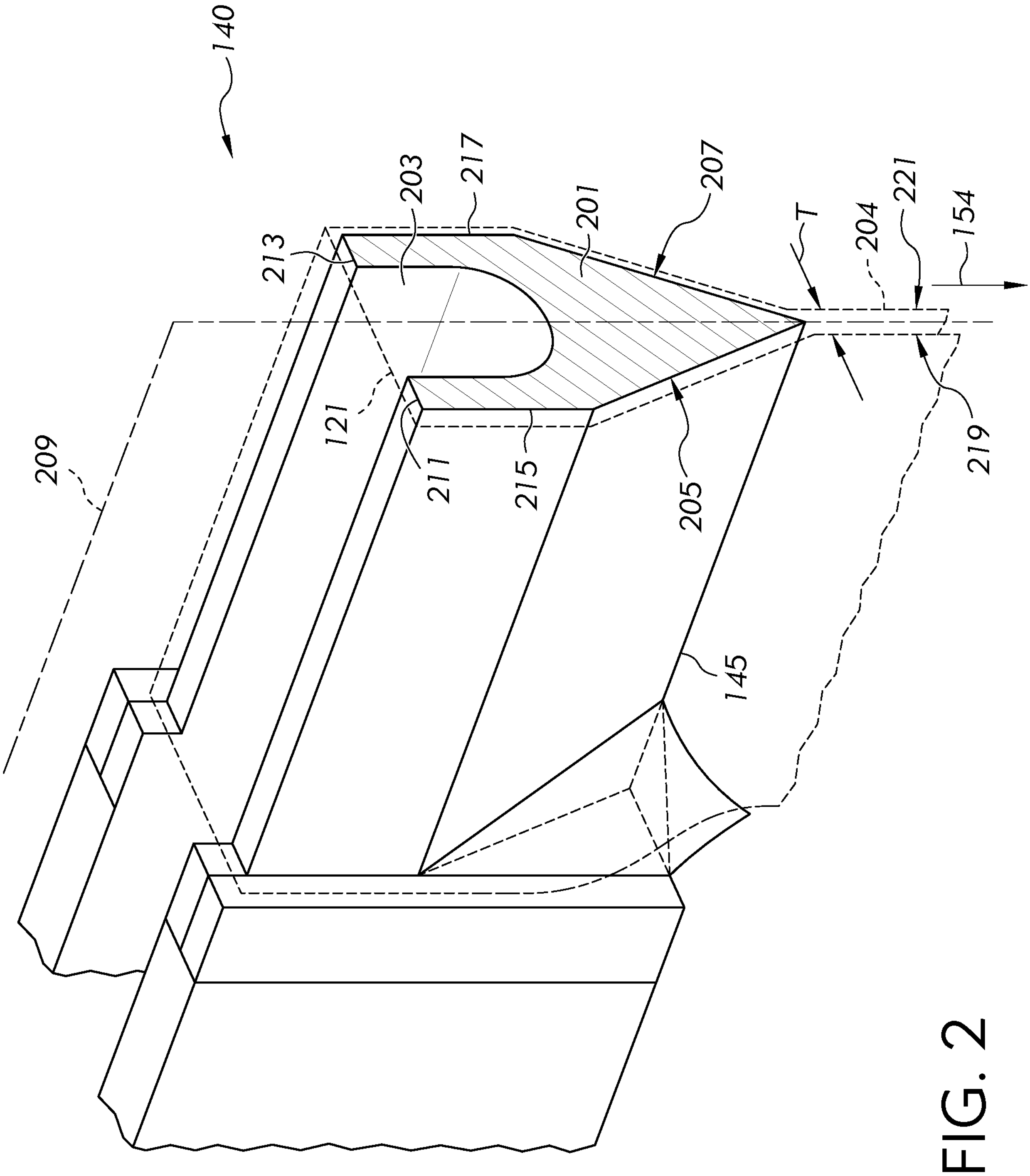
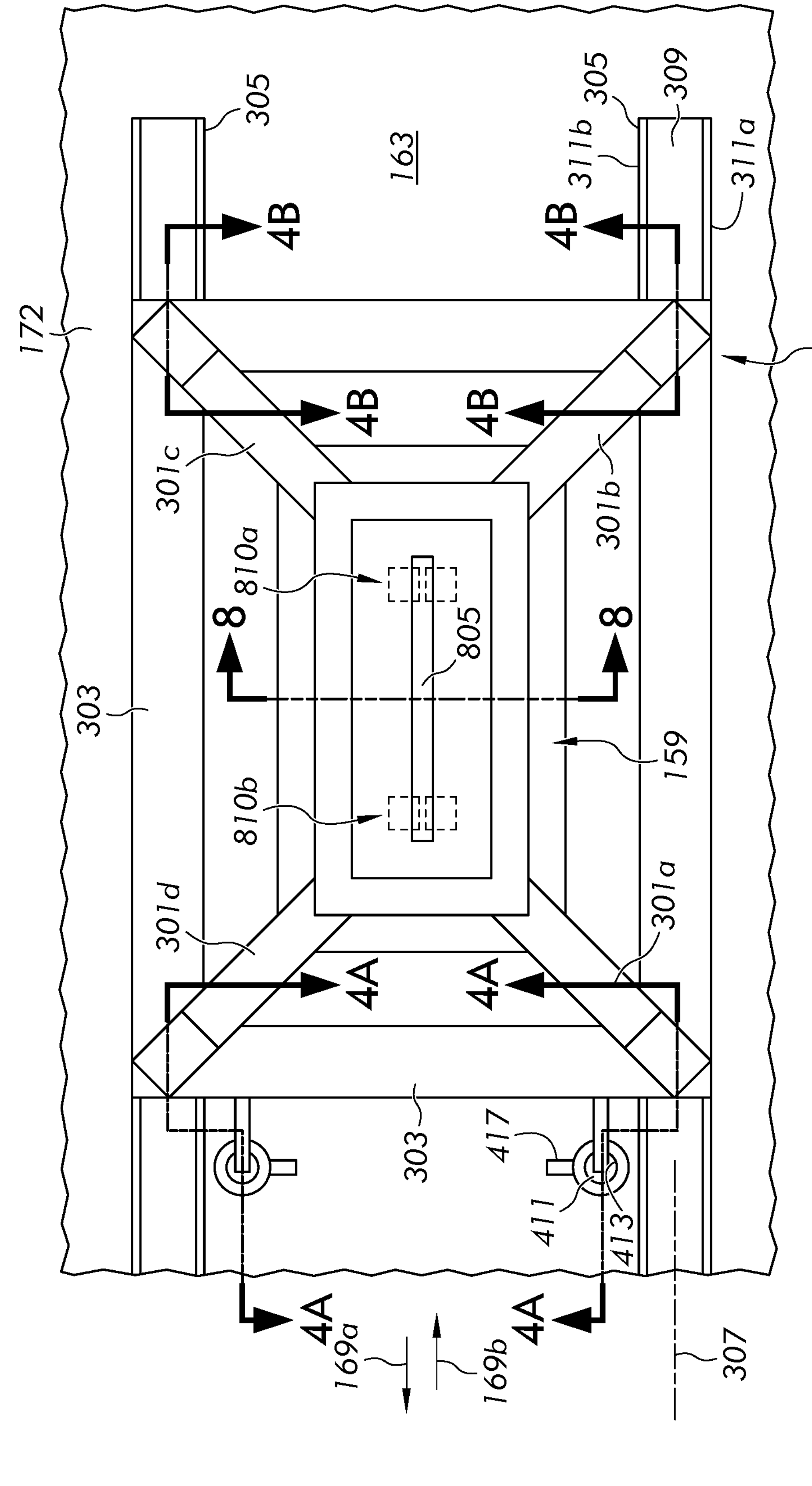


FIG. 2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169a
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FIG. 3

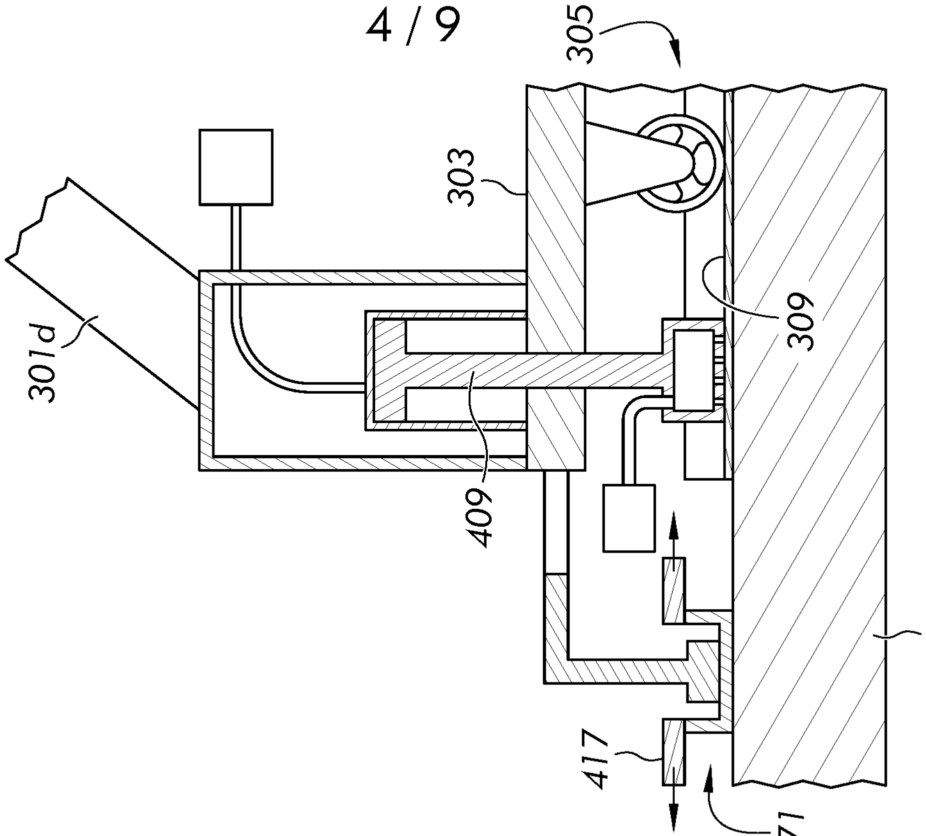
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FIG. 5

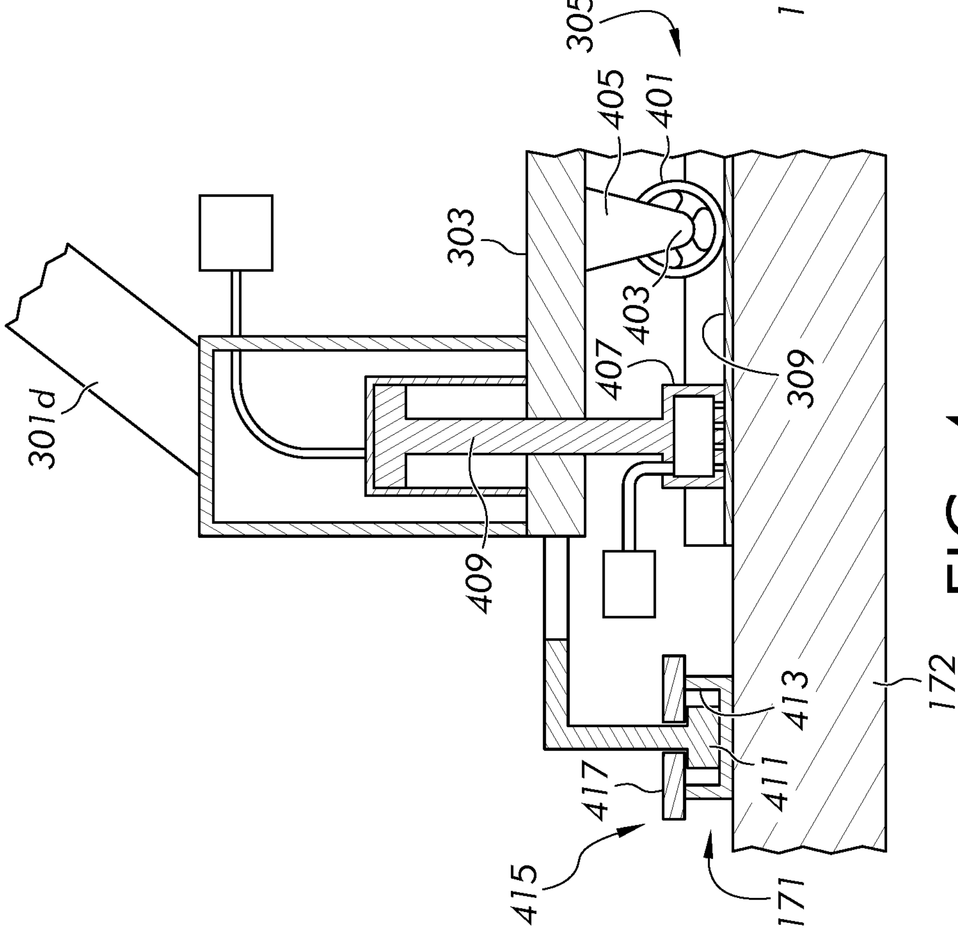
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FIG. 4

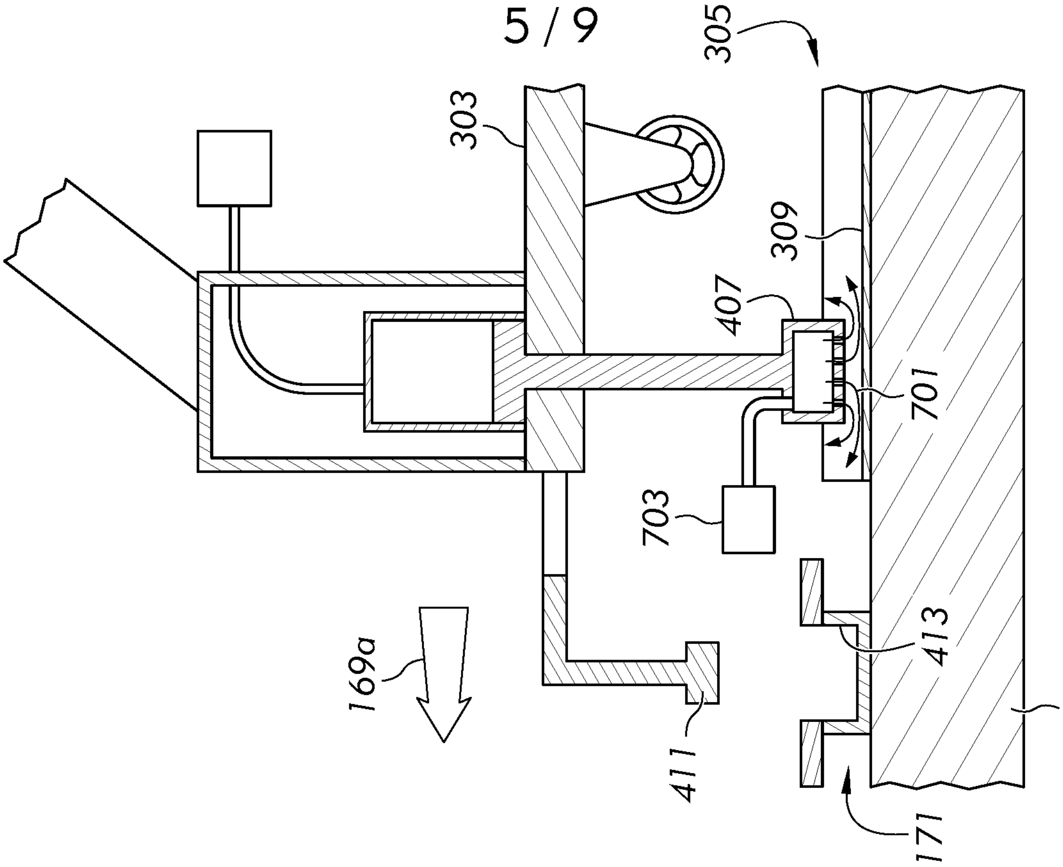
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FIG. 7

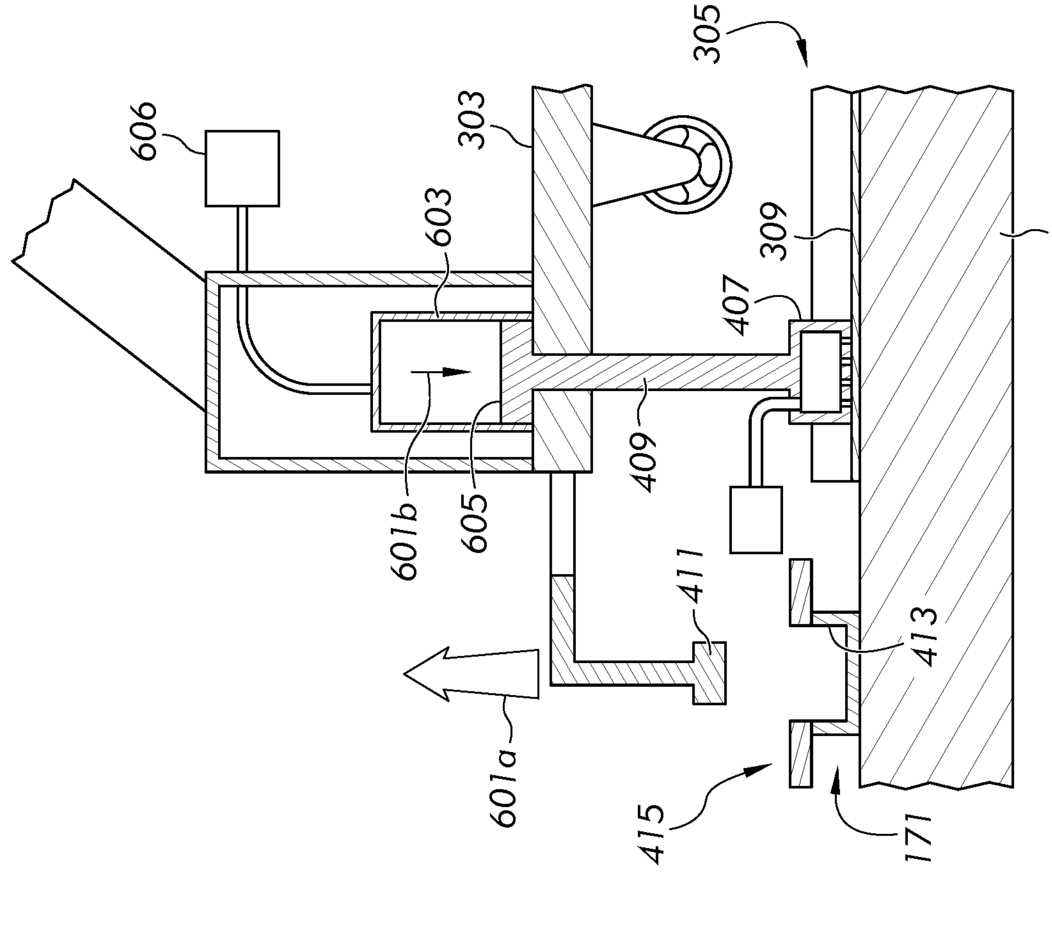
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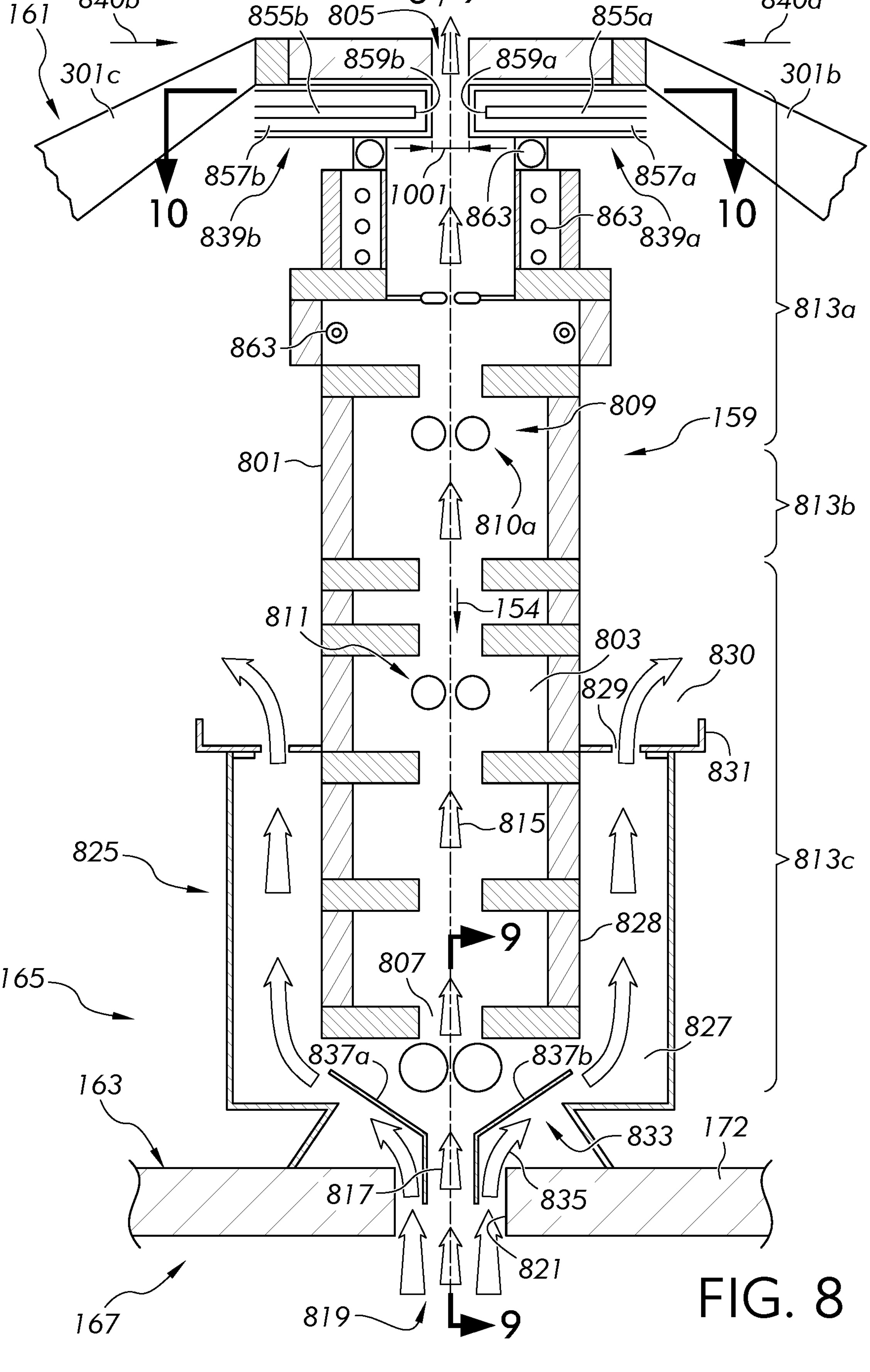
FIG. 6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863
809
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813c
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FIG. 8

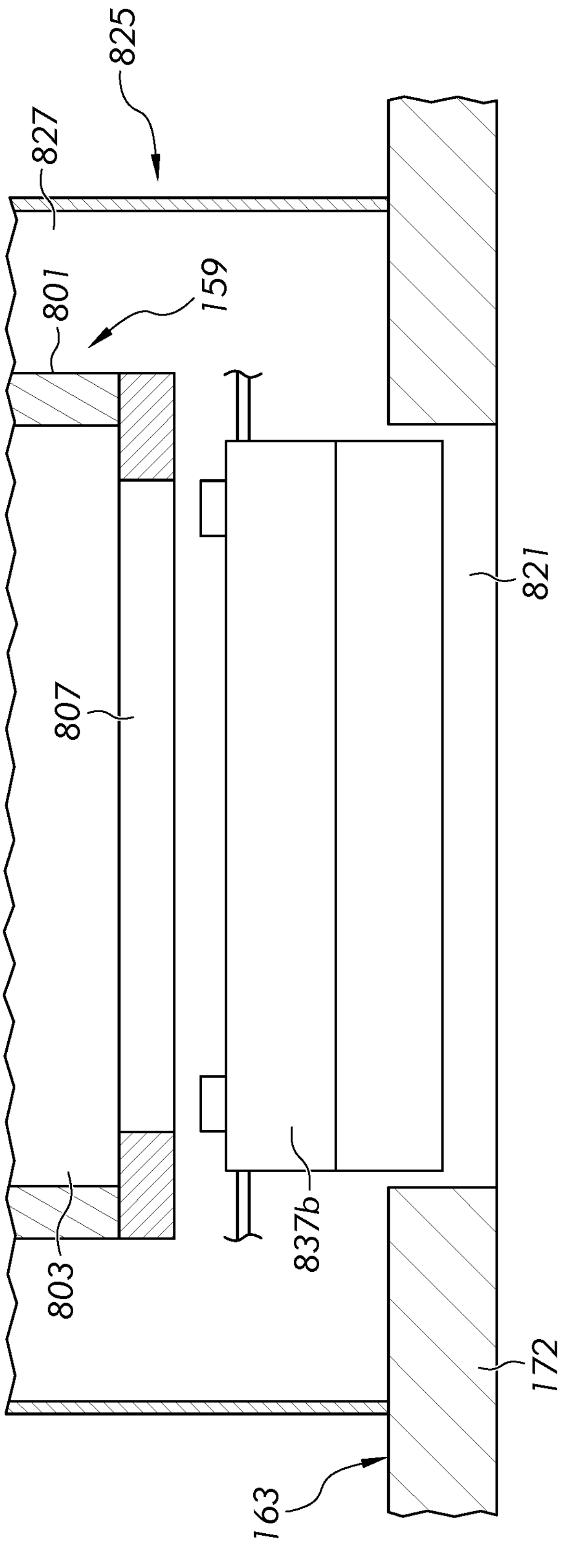

FIG. 9

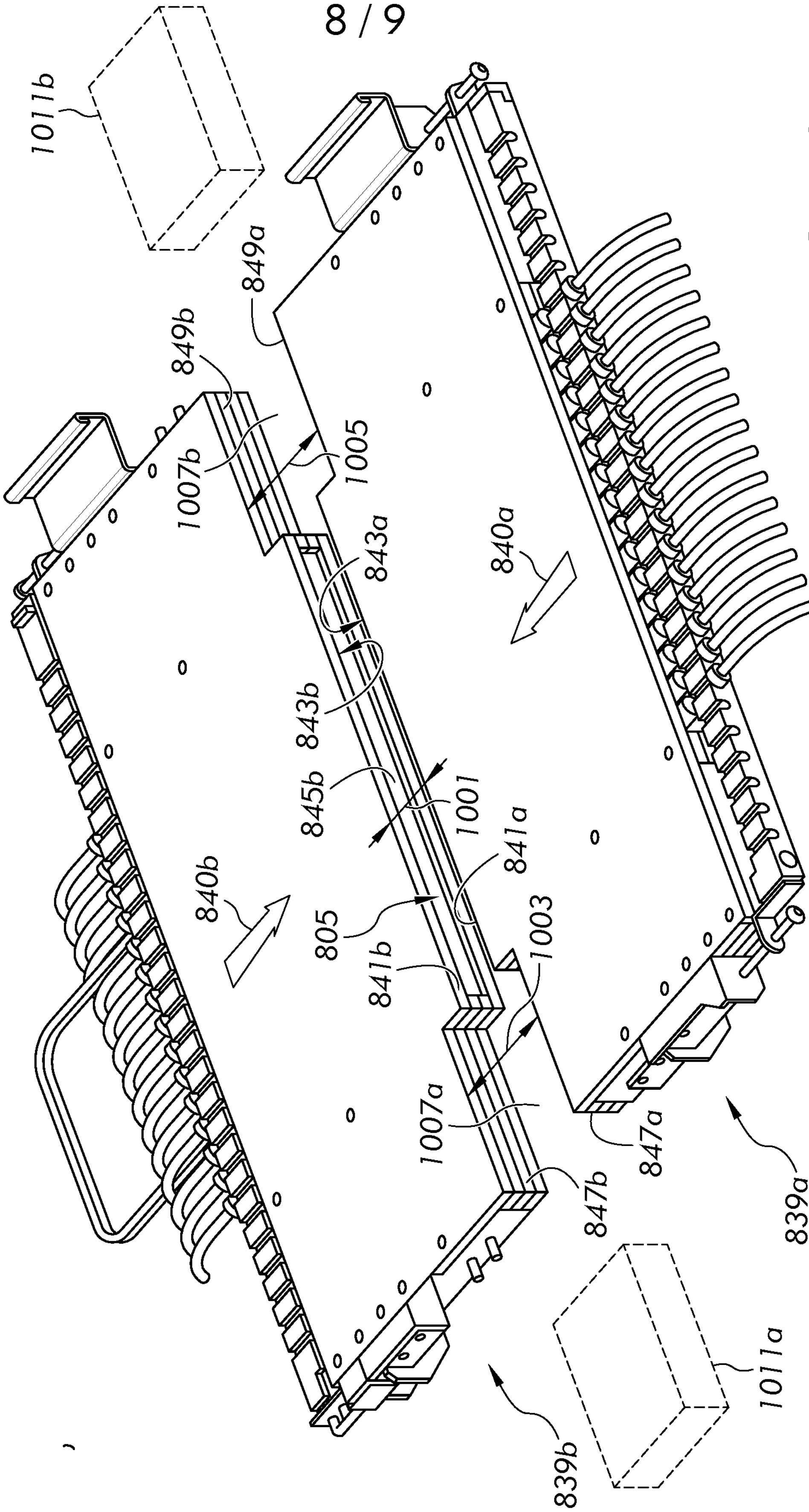
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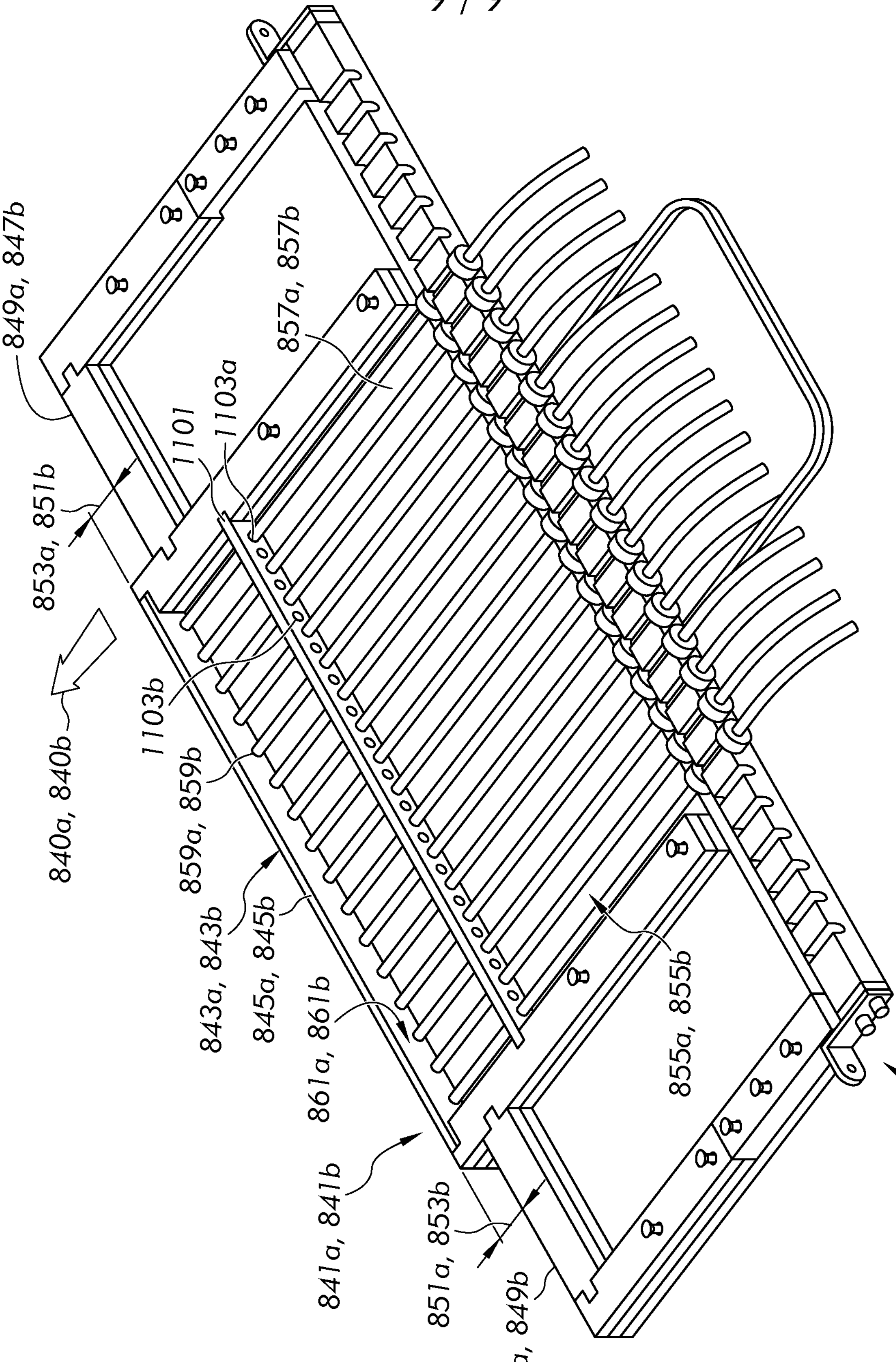
FIG. 10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851a, 853b
847a, 849b
855a, 855b
839a, 839b

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2022/011084

A. CLASSIFICATION OF SUBJECT MATTER
INV. C03B17/06
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2002 167226 A (ASAHI GLASS CO LTD) 11 June 2002 (2002-06-11) Figures,items 36,34,64,14,60,42, 46 and 38 and 0016; claims 1-2	1-12
A	WO 2017/095791 A1 (CORNING INC [US]) 8 June 2017 (2017-06-08) fgures	1

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

☒ See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 April 2022	21/06/2022

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Gkerou, Elisavet

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2022/011084

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

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

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

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

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

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

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

see additional sheet

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

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

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

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims;; it is covered by claims Nos.:
1-12

Remark on Protest

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

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

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

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

1. claims: 1-12

   Independent claim 1 directed to an apparatus of forming a glass ribbon comprising a movable in the vertical direction draw stack.

   ---

2. claims: 13-19

   Independent claim 13 directed to an apparatus for forming a glass ribbon comprising a draw stack and a housing with a vent.

   ---

3. claims: 20-30

   Independent claim 20 directed to a draw stack for forming a glass ribbon comprising first and second gates defining width of inlet.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2022/011084

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2002167226 A	11-06-2002	NONE	
WO 2017095791 A1	08-06-2017	CN 108290763 A	17-07-2018
		JP 6906519 B2	21-07-2021
		JP 2019500302 A	10-01-2019
		KR 20180080353 A	11-07-2018
		TW 201730119 A	01-09-2017
		WO 2017095791 A1	08-06-2017