(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
12 October 2017 (12.10.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/176868 A1

(51) International Patent Classification: *C03B 15/02* (2006.01)

(21) International Application Number: PCT/US2017/026116

(22) International Filing Date: 5 April 2017 (05.04.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/318,295 5 April 2016 (05.04.2016) US

(71) Applicant: **CORNING INCORPORATED** [US/US]; 1 Riverfront Plaza, Corning, New York 14831 (US).

(72) Inventor: **AGRAWAL, Anmol**; 207 Claire Blvd., Horseheads, New York 14845 (US).

(74) Agent: **MASON, Matthew J**; Corning Incorporated, Intellectual Property Department, SP-Ti-03-01, Corning, New York 14831 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) Title: METHODS AND APPARATUS FOR PRODUCING A GLASS RIBBON

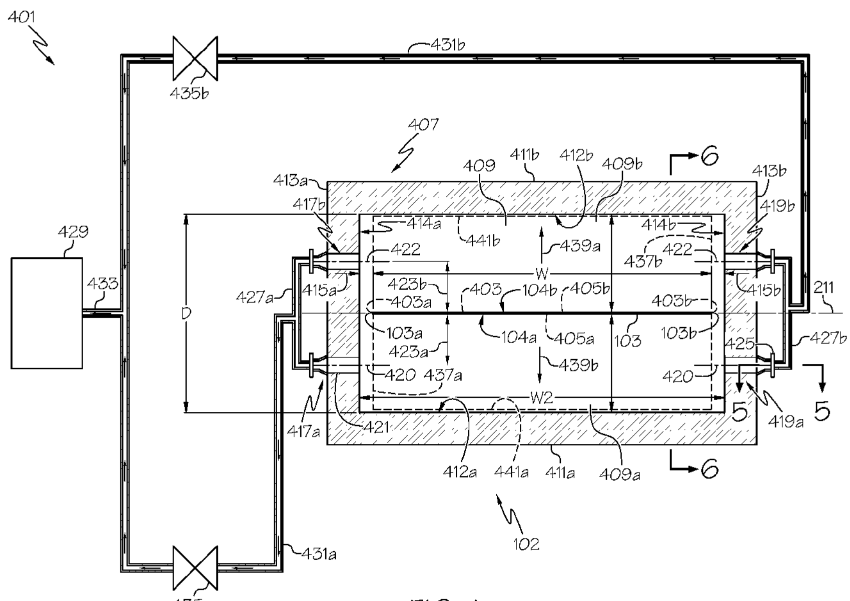

FIG. 4

(57) Abstract: Methods of producing a glass ribbon each includes drawing a glass ribbon along a draw direction and applying a vacuum only to at least one vacuum port located laterally outside of at least one of the opposed edges of the glass ribbon to promote convection cooling of the glass ribbon with a cooling fluid flow generated at least partially by the vacuum being applied to the at least one vacuum port. In further embodiments, draw apparatus includes at least one vacuum port including a passage extending through one of a first end wall and a second end wall of the shroud. Each of the first end wall and the second end wall are located laterally outside a corresponding one of a first lateral end and a second lateral end of a transverse cross section of a draw path.

WO 2017/176868 A1

METHODS AND APPARATUS FOR PRODUCING A GLASS RIBBON

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 62/318295 filed on April 5, 2016, the content of which is relied upon and incorporated herein by reference in its entirety.

FIELD

[0002] The present disclosure relates generally to apparatus and methods for producing glass ribbon and, more particularly, to apparatus and methods for producing a glass ribbon with at least one vacuum source configured to promote convection cooling of the glass ribbon by forcing a cooling fluid to flow along the glass ribbon.

BACKGROUND

[0003] It is known to draw a glass ribbon with a draw device. The glass ribbon may be subsequently divided to produce a plurality of glass sheets that may be employed in a wide range of applications. The glass ribbon is known to be drawn in a viscous state for eventual cooling into an elastic state where final features are permanently set into the glass sheet.

[0004] WIPO publication No. WO2014/193780 that published December 4, 2014 to Welles (hereinafter the Welles publication) discloses a plurality of vacuum ports laterally disposed along major surfaces of a glass ribbon. A first set of multiple vacuum ports associated with the first major surface of the glass ribbon are in communication with a first vacuum plenum conduit to provide pressure uniformity across the first set of multiple vacuum ports. Likewise, a second set of multiple vacuum ports associated with the second major surface of the glass ribbon are in communication with a second vacuum plenum conduit to provide pressure uniformity across the second set of multiple vacuum ports. The multiple vacuum port design of the Welles publication can provide desired cooling of the glass ribbon in various applications. In operation, the glass ribbon of the Welles publication may be drawn at a glass ribbon mass flow rate "**Mglass**" and the cooling fluid flow through all of the multiple vacuum ports may be drawn at a combined mass flow rate "**Mair**". For example, **FIG. 7** of the instant application demonstrates simulated test results associated with cooling the glass ribbon with a cooling apparatus similar to the multiple vacuum port design of the Welles publication discussed above. Specifically, **FIG. 7**

is a simulation showing changes in a temperature difference between: (1) natural cooling without use of the multiple vacuum port design of the Welles publication; and (2) forced cooling using the multiple vacuum port design similar to the Welles publication discussed above at a ratio of "**Mair**" with respect to "**Mglass**" (i.e., **Mair/Mglass**) of 0.179 with all the vacuum ports opened. Throughout **FIGS. 7-9**, the vertical axis ("y" axis) represents the distance, in inches, below the root of the forming wedge while the horizontal axis ("x" axis) represents the distance, in inches, from the glass ribbon center. **FIG. 7** demonstrates desirable results, at least from 114.3 centimeters (45 inches) to 177.8 centimeters (70 inches) below the root of the forming wedge. Indeed, as shown, temperature difference contours **701a-f** extend substantially along respective uniform horizontal pressure differential paths through a central portion [e.g., ± 50.8 centimeters (20 inches) from the glass ribbon center] of the width of the glass ribbon, indicating the temperature difference remains substantially constant across the width of the central portion of the glass ribbon. However, in some examples, the multiple vent port design of the Welles publication may present problems such as too many control variables, higher costs of the relatively complex system, difficulty of operation, and the possibly oversized vacuum plenum conduits that contribute to a relatively large footprint of the multiple vent port design and may obstruct access to areas of the multiple vent port design. Moreover, in some embodiments, the vacuum ports of the Welles publication may act as a heat sink since they face the major surface of the glass ribbon. In some embodiments, there may be a desire to move the vacuum ports laterally outside of the edges of the glass ribbon so that the vacuum ports do not face the major surfaces of the glass ribbon and therefore do not act as a heat sink across a major surface of the glass ribbon. As such, undesirable uneven cooling of the glass ribbon may be avoided by moving the vacuum ports so they do not face the major surface of the glass ribbon.

[0005] **FIG. 8** is a simulation similar to **FIG. 7** associated with a simplified multiple vacuum port design similar to the Welles publication discussed above but where only the central two vacuum ports are open with the remaining vent ports turned off. In other words, **FIG. 8** provides a simulation similar to the simulation of **FIG. 7** with the ratio **Mair/Mglass** of 0.179 but only removing the cooling fluid flow from the interior of the shroud only with the central two ports associated with the central portion of each of the two major surfaces of the glass ribbon rather than all of the ports extending across the width of the glass ribbon. **FIG. 8** also demonstrates desirable results at least from about 114.3 centimeters (45 inches) to about 165.1

centimeters (65 inches) below the root of the forming wedge. Indeed, as shown, temperature difference contours **801a-d** likewise extend substantially along respective uniform horizontal pressure differential paths through a central portion [e.g., ± 50.8 centimeters (20 inches) from the glass ribbon center] of the width of the glass ribbon. The test results of **FIG. 8** suggest that the multiple vent port design of the Welles publication discussed above may be simplified to only include two functional ports on each side near the center of the glass ribbon. The simplified multiple vent port design of the Welles publication discussed above may thereby provide a substantially constant temperature difference across a width of the central portion of the glass ribbon while avoiding the problems or reducing the severity of the problems that may be associated with the more complex design using all of the vents of the multiple vent port design of the Welles publication discussed above.

[0006] There is an increased desire in some applications to increase the rate at which the glass ribbon is drawn from the forming wedge to increase the production rate of the glass ribbon. Such increased draw rates require increased cooling in order to maintain the size of the glass forming apparatus. Indeed, without increased cooling, drawing the glass ribbon at a faster rate may require lengthening the cooling apparatus at great expense to adequately cool the glass ribbon before the glass ribbon exits the cooling apparatus.

[0007] In some instances, the simplified multiple vent port design of the Welles publication discussed above (i.e., with only the central two portions on each side of the glass ribbon in operation) may not provide a substantially constant temperature difference across the width of the central portion of the glass ribbon at increased rates of gas removal from the interior of the shroud. For example, **FIG. 9** simulates how the simplified multiple vent port design of the Welles publication (associated with the test results of **FIG. 8**) would perform with a ratio **Mair/Mglass** of 1.071 while only removing the cooling fluid flow with the central two ports associated with each of the two major surfaces of the glass ribbon. As can be seen in **FIG. 9**, the temperature difference contours **901a-c** in the central portion [e.g., ± 50.8 centimeters (20 inches) from the glass ribbon center] of a width of the glass ribbon are relatively jagged and do not extend respective uniform horizontal pressure differential paths. As evidenced by **FIG. 9**, the temperature difference at the higher gas removal rate is not constant across the entire width of the glass ribbon and therefore may provide an ineffective design. In order to accommodate higher gas removal rates for higher convection cooling of the glass ribbon, there is a need to provide a cooling apparatus that can accommodate a wide range gas removal rates (e.g., relatively high cooling rates) with temperature differentials being substantially constant across a central portion of the glass ribbon. There is also a desire to provide a cooling apparatus that is: (1) easier to operate with less control variables; (2) inexpensive to produce; (3) reduced in size with a minimal footprint; (4) easily accessible; and/or (5) minimize the exposure of the major surface(s) of the glass ribbon to a heat sink due to vacuum ports facing the major surface(s).

SUMMARY

[0008] The following presents a simplified summary of the disclosure in order to provide a basic understanding of some example aspects described in the detailed description.

[0009] Example apparatus and methods of the present disclosure provide convection heat transfer by producing convection currents that expose the glass sheet to cooling air or other gases to promote convection cooling of the glass ribbon. The convection currents are produced by using a vacuum source to cause a cooling fluid to flow along the glass ribbon. Such convection cooling systems can provide effective cooling at locations downstream from the drawing device and/or with glass that is being drawn at lower temperatures.

[0010] In one embodiment, a method of producing a glass ribbon can include drawing a glass ribbon along a draw direction. The glass ribbon may include a first major surface and a second major surface. Each of the first major surface and the second major surface may extend between opposed edges of the glass ribbon. The method can further include applying a vacuum only to at least one vacuum port located laterally outside of at least one of the opposed edges of the glass ribbon to promote convection cooling of the glass ribbon with a cooling fluid flow generated at least partially by the vacuum being applied to the at least one vacuum port.

[0011] In another embodiment, the method may further include contacting at least one of the first major surface and the second major surface of the glass ribbon with the cooling fluid flow.

[0012] In another embodiment, applying the vacuum may promote an upstream portion of the cooling fluid flow to travel along an upstream flow direction that is substantially opposite to the draw direction.

[0013] In another embodiment, applying the vacuum may promote a downstream portion of the cooling fluid flow to travel along a downstream flow direction that extends across the draw direction.

[0014] In another embodiment, the method may further include drawing the glass ribbon at a glass ribbon mass flow rate (Mglass) and drawing the cooling fluid flow through all of the at least one vacuum port at a combined mass flow rate (Mair), wherein a ratio of Mair with respect to Mglass is within a range of from about 0.036 to about 7.143.

[0015] In another embodiment, the ratio of Mair with respect to Mglass is within a range of from about 0.357 to about 2.143.

[0016] In another embodiment, the ratio of Mair with respect to Mglass is within a range of from about 0.357 to about 1.071.

[0017] In another embodiment, the glass ribbon may be drawn by fusion drawing the glass ribbon from a root of a forming wedge.

[0018] In another embodiment, a draw apparatus for producing a glass ribbon can include a draw path for a glass ribbon defined by the draw apparatus. The draw path can be positioned along a draw direction of the draw apparatus. The draw path can include a transverse cross section taken perpendicular to the draw direction. The draw apparatus can further include a shroud circumscribing the transverse cross section of the draw path. The draw apparatus can still further include at least one vacuum port including a passage extending through one of a first end wall and a second end wall of the shroud. At least one vacuum port may include a passage extending through one of a first end wall and a second end wall of the shroud. A first lateral end of the transverse cross section of the draw path can face the first end wall of the shroud and second lateral end of the transverse cross section of the draw path can face the second end wall of the shroud. Furthermore, the first end wall of the shroud may be located laterally outside of the first lateral end of the transverse cross section of the draw path and the second end wall of the shroud may be located laterally outside of the second lateral end of the transverse cross section of the draw path.

[0019] In another embodiment, the at least one vacuum port may consist of all of the vacuum ports of the draw apparatus.

[0020] In another embodiment, the at least one vacuum port can include at least one vacuum port in the first end wall and at least one vacuum port in the second end wall.

[0021] In another embodiment, the at least one vacuum port may include two vacuum ports in the first end wall.

[0022] In another embodiment, a plane passing through the first lateral end and the second lateral end may extend between the two vacuum ports.

[0023] In another embodiment, the at least one vacuum port may further include two additional vacuum ports in the second end wall.

[0024] In another embodiment, a plane passing through the first lateral end and the second lateral end may extend between the two vacuum ports in the first end wall and the two additional vacuum ports in the second end wall.

[0025] In another embodiment, a glass apparatus can include a glass ribbon and a draw apparatus. The glass ribbon can include a first major surface and a second major surface, and each of the first major surface and the second major surface may extend between opposed edges of the glass ribbon. The glass ribbon may further extend through the draw path. A first edge of the opposed edges of the glass ribbon can face the first end wall of the shroud and a second edge of the opposed edges of the glass ribbon can face the second end wall of the shroud. The first major surface of the glass ribbon can face a first sidewall of the shroud and the second major surface of the glass ribbon can face a second sidewall of the shroud.

[0026] In another embodiment, neither the first sidewall of the shroud nor the second sidewall of the shroud includes a vacuum port.

[0027] In another embodiment, a fluid intake axis of the at least one vacuum port may be substantially parallel to the first major surface and the second major surface of the glass ribbon.

[0028] In another embodiment, the glass ribbon may extend along a draw plane of the draw path, wherein the at least one vacuum port is offset from the draw plane.

[0029] In another embodiment, a glass apparatus can include a glass ribbon, a shroud, and at least one vacuum port. The glass ribbon may extend along a draw direction and can include a first major surface and a second major surface. Each of the first major surface and the second major surface may extend between opposed edges of the glass ribbon. A plane of the glass ribbon can extend in the draw direction and through the opposed edges of the glass ribbon. The shroud may include an interior surface circumscribing a length of the glass ribbon extending along the draw direction. A first area of the interior surface can be defined by a projection of the first major surface in a first direction perpendicular to the plane. A second area of the interior surface can be defined by a projection of the second major surface in a second direction perpendicular to the plane and opposite the first direction. The at least one vacuum port can include a passage extending through the interior surface of the shroud at a location outside of the first and second area of the interior surface.

[0030] In another embodiment, the at least one vacuum port may consist of all of the vacuum ports of the draw apparatus.

[0031] In another embodiment, the shroud may include a first sidewall including the first area of the interior surface, a second sidewall including the second area of the interior surface, a first end wall joining a first end of the first sidewall and a first end of the second sidewall, and a second end wall joining a second end of the first sidewall and a second end of the second sidewall.

[0032] In another embodiment, the at least one vacuum port may be located in at least one of the first end wall, the second end wall, the first sidewall and the second sidewall.

[0033] In another embodiment, the at least one vacuum port may be located in at least one of the first end wall and the second end wall.

[0034] In another embodiment, the at least one vacuum port can include two vacuum ports in the first end wall.

[0035] In another embodiment, the plane can pass between the two vacuum ports in the first sidewall.

[0036] In another embodiment, the at least one vacuum port may include two additional vacuum ports in the second end wall.

[0037] In another embodiment, the plane may pass between the two vacuum ports in the first end wall and the two additional vacuum ports in the second end wall.

[0038] In another embodiment, neither the first sidewall of the shroud nor the second sidewall of the shroud includes a vacuum port.

[0039] In another embodiment, a fluid intake axis of the at least one vacuum port may be substantially parallel to the first major surface and the second major surface of the glass ribbon.

[0040] In another embodiment, the at least one vacuum port can be offset from the plane.

BRIEF DESCRIPTION OF THE DRAWINGS

[0041] These and other features, aspects and advantages of the claimed invention are better understood when the following detailed description is read with reference to the accompanying drawings, in which:

[0042] **FIG. 1** is a schematic illustration of an example glass apparatus in accordance with embodiments of the disclosure;

[0043] **FIG. 2** illustrates a sectional view of the glass apparatus along line 2-2 of **FIG. 1**;

[0044] **FIG. 3** schematically illustrates a glass ribbon being drawn off a forming wedge of the example glass apparatus of **FIG. 1**;

[0045] **FIG. 4** illustrates a sectional view of an example convection cooling device of the glass apparatus along line 4-4 of **FIG. 1**;

[0046] **FIG. 5** is a cross sectional view along line 5-5 of **FIG. 4**, illustrating example features of the convection cooling device of **FIG. 4**;

[0047] **FIG. 6** illustrates a schematic view of a glass apparatus in accordance with embodiments of the disclosure; and

[0048] **FIGS. 7-14** demonstrate simulated test results associated with cooling a glass ribbon.

DETAILED DESCRIPTION

[0049] Aspects of the claimed invention will now be described more fully hereinafter with reference to the accompanying drawings in which example embodiments of the claimed invention are shown. Whenever possible, the same reference numerals are used throughout the drawings to refer to the same or like parts. However, the claimed invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. These example embodiments are provided so that this disclosure will be both thorough and complete, and will fully convey the scope of the claimed invention to those skilled in the art.

[0050] Apparatus of the disclosure can comprise the illustrated glass apparatus **101** including a draw apparatus **102** and a glass ribbon **103** being drawn from the draw apparatus. As shown in **FIG. 2**, the glass ribbon **103** includes a first major surface **104a** and a second major surface **104b** extending between a first lateral edge **103a** and a second lateral edge **103b** with a thickness "**T**" between the edges of from about 50 microns to about 750 microns. In further embodiments, the thickness "**T**" is from about 100 microns to 500 microns. In still further embodiments, the thickness "**T**" is from about 200 microns to about 400 microns and can be about 300 microns in further embodiments.

[0051] In the illustrated example, the draw apparatus **102** can comprise the illustrated fusion down-draw apparatus although other down-draw apparatus, up-draw apparatus, slot-draw apparatus, float apparatus, press-roll apparatus or other draw apparatus may be incorporated with the glass apparatus **101** in further embodiments. With such glass ribbon forming techniques, the present disclosure provides for control of viscosity and temperature cooling curves to provide process stability and facilitate quality performance. For instance, in the illustrated glass apparatus **101**, proper cooling below a forming vessel **143** can help provide the glass ribbon with sufficient cooling and high-enough viscosity to minimize ribbon bagginess, i.e., the tendency of the ribbon to deform uncontrollably, such as unevenly under its own weight. Proper cooling below the forming vessel **143** can also help stabilize thickness and provide shape control. Furthermore, proper cooling can help provide appropriate transitioning and conditioning of the glass ribbon into the visco-elastic region where final glass ribbon flatness, stress, and shape is controlled.

[0052] FIG. 1 illustrates possible features of the glass apparatus **101** in accordance with just one embodiment of the disclosure. The glass apparatus **101** can include a melting vessel **105**

configured to receive batch material **107** from a storage bin **109**. The batch material **107** can be introduced by a batch delivery device **111** powered by a motor **113**. An optional controller **115** can be configured to activate the motor **113** to introduce a desired amount of batch material **107** into the melting vessel **105**, as indicated by arrow **117**. A metal probe **119** can be used to measure a free surface of a glass melt **121** within a standpipe **123** and communicate the measured information to the controller **115** by way of a communication line **125**.

[0053] The glass apparatus **101** can also include a fining vessel **127**, such as a fining tube, located downstream from the melting vessel **105** and coupled to the melting vessel **105** by way of a first connecting tube **129**. A mixing vessel **131** such as a stir chamber, can also be located downstream from the fining vessel **127** and a delivery vessel **133** may be located downstream from the mixing vessel **131**. As shown, a second connecting tube **135** can couple the fining vessel **127** to the mixing vessel **131** and a third connecting tube **137** can couple the mixing vessel **131** to the delivery vessel **133**. As further illustrated, a downcomer **139** can be positioned to deliver glass melt **121** from the delivery vessel **133** to the draw apparatus **102**. In the illustrated example of the glass apparatus **101**, the draw apparatus **102** can comprise the forming vessel **143** provided with an inlet **141** to receive glass melt from the downcomer **139**.

[0054] As shown, the melting vessel **105**, fining vessel **127**, the mixing vessel **131**, delivery vessel **133**, and forming vessel **143** are examples of glass melt stations that may be located in series along the glass apparatus **101**.

[0055] The melting vessel **105** is typically made from a refractory material, such as refractory (e.g. ceramic) brick. The glass apparatus **101** may further include components that are typically made from platinum or platinum-containing metals such as platinum-rhodium, platinum-iridium and combinations thereof, but which may also comprise such refractory metals such as molybdenum, palladium, rhenium, tantalum, titanium, tungsten, ruthenium, osmium, zirconium, and alloys thereof and/or zirconium dioxide. The platinum-containing components can include one or more of the first connecting tube **129**, the fining vessel **127** (e.g., finer tube), the second connecting tube **135**, the standpipe **123**, the mixing vessel **131** (e.g., a stir chamber), the third connecting tube **137**, the delivery vessel **133** (e.g., a bowl), the downcomer **139** and the inlet **141**. The forming vessel **143** is also made from a refractory material and is designed to form the glass ribbon **103**.

[0056] **FIG. 2** is a cross-sectional perspective view of the example glass apparatus **101** along line 2-2 of **FIG. 1**. As shown, the forming vessel **143** includes a forming wedge **201** comprising a pair of downwardly inclined forming surface portions **203**, **205** extending between opposed ends of the forming wedge **201**. The pair of downwardly inclined forming surface portions **203**, **205** converge along a draw direction **207** to form a root **209**. A draw plane **211** of the glass apparatus **101** extends through the root **209** wherein the glass ribbon **103** may be drawn in the draw direction **207** along the draw plane **211** of the glass apparatus **101**. As shown, the draw plane **211** of the glass apparatus **101** can bisect the root **209** although the draw plane **211** of the glass apparatus **101** may extend at other orientations with respect to the root **209**.

[0057] The glass apparatus **101** can also include at least one edge roller assembly including a pair of edge rollers configured to engage a corresponding one of a first lateral edge **103a** and a second lateral edge **103b** of the glass ribbon **103** as the ribbon is drawn off the root **209** of the forming wedge **201**. The pair of edge rollers facilitates proper finishing of the edges of the glass ribbon. Edge roller finishing provides desired edge characteristics and proper fusion of the edge portions of the molten glass being pulled off opposed surfaces of an edge director **212** associated with the pair of downwardly inclined forming surface portions **203**, **205**. As shown in **FIGS. 2 and 3**, a first edge roller assembly **213a** is associated with the first lateral edge **103a** and, as further shown in **FIG. 3**, a second edge roller assembly **213b** is associated with the second lateral edge **103b** of the glass ribbon **103**. Each edge roller assembly **213a**, **213b** can be substantially identical to one another although the pairs of edge rollers may have different characteristics in further examples.

[0058] As shown in **FIG. 3**, the glass apparatus **101** can further include a first and second pull roll assembly **301a**, **301b** for each respective first lateral edge **103a** and second lateral edge **103b** to facilitate pulling of the glass ribbon **103** in the draw direction **207** along the draw plane **211** of the glass apparatus **101**.

[0059] The glass apparatus **101** can further include a cutting device **303** that allows the glass ribbon **103** to be cut into distinct glass sheets **305**. The glass sheets **305** may be subdivided into individual glass sheets for incorporating in the various display devices, such as liquid crystal displays (LCDs), electrophoretic displays (EPD), organic light emitting diode displays (OLEDs), and plasma display panels (PDPs). Cutting devices may include laser devices, mechanical scoring devices, traveling anvil machines and/or other devices configured to cut the glass ribbon **103** into the distinct glass sheets **305**.

[0060] Referring to **FIG. 2**, in one example, the glass melt **121** can flow into a trough **215** of the forming vessel **143**. The glass melt **121** can then simultaneously flow over corresponding weirs **217a**, **217b** and downward over the outer surfaces **219a**, **219b** of the corresponding weirs **217a**, **217b**. Respective streams of glass melt then converge along the downwardly inclined forming surface portions **203**, **205** to the root **209** of the forming vessel **143**. The glass ribbon **103** is then drawn off the root **209** in the draw plane **211** along draw direction **207**.

[0061] Turning to **FIG. 3**, the glass ribbon **103** is drawn from the root **209** in the draw direction **207** from a viscous zone **307** to a setting zone **309**. In the setting zone **309**, the glass ribbon **103** is set from a viscous state to an elastic state with the desired cross-sectional profile. The glass ribbon is then drawn from the setting zone **309** to an elastic zone **311**. In the elastic zone **311**, the profile of the glass ribbon from the viscous zone **307** is frozen as a characteristic of the glass ribbon. While the set ribbon may be flexed away from this configuration, internal stresses can cause the glass ribbon to bias back to the original set profile in the elastic state. In contrast, while the ribbon may also be flexed away in a viscous state, internal stresses are lacking to cause the glass ribbon to bias back to the original state prior to flexing away from the original configuration.

[0062] As shown in **FIG. 3**, the glass apparatus **101** can comprise a fusion draw machine **313** provided with each edge roller assembly **213a**, **213b** and the first and second pull roll assembly **301a**, **301b**. The glass ribbon can further be drawn below the fusion draw machine **313** by a distance **150** before being cut into the individual sheets **305**.

[0063] Any of the draw apparatus **102** of the disclosure can include a convection cooling device **401**, schematically illustrated in **FIG. 4**, configured to promote convection cooling of the glass ribbon by forcing a cooling fluid (e.g., vapor, gas such as air, etc.) to flow along the glass ribbon **103**. The convection cooling device can be positioned to cool the glass ribbon **103** by way of convection in the setting zone **309** and/or the elastic zone **311**. For example, as shown schematically by dashed lines **401a** in **FIGS. 1 and 2**, the convection cooling device **401** can be positioned to cool the glass ribbon within at least a portion of the setting zone **309** and at least a portion of the elastic zone **311**. Alternatively, as schematically shown by dashed lines **401b** in

FIG. 1, the convection cooling device **401** can be positioned to cool the glass ribbon only within at least a portion of the elastic zone **311**. For example, as schematically shown by dashed lines **401c** in **FIG. 3**, the convection cooling device **401** can be positioned to cool the glass ribbon only within at least a portion of the elastic zone **311** that is positioned entirely below the fusion draw machine **313** although the convection cooling device may be positioned partially or entirely within the fusion draw machine in further examples.

[0064] Some embodiments of the disclosure include the glass apparatus **101** that includes the draw apparatus **102** in combination with the glass ribbon **103**. In further embodiments, the glass apparatus **101** includes the draw apparatus **102** for drawing the glass ribbon **103** during a draw procedure. Embodiments of the disclosure can provide the draw apparatus **102** with a convection cooling device. **FIG. 4** is a schematic view of one embodiment of a convection cooling device **401** of the draw apparatus **102** taken along line 4-4 of **FIG. 1**. As shown, the draw apparatus **102** can include a draw path **403** defined by the draw apparatus **102** for the glass ribbon **103**.

[0065] In some examples, the draw path may include a portion of the draw plane **211** extending below the root wherein a width of the draw path between the first lateral end **403a** and the second lateral end **403b** of the draw path is equal to a width of the location where the ribbon is drawn from the forming device. For instance, referring to **FIG. 3**, in the illustrated embodiment, the width of the draw path can may be equal to a width "**W1**" of the forming wedge **201**, a width of the root, or a portion of the width of the root extending between the edge directors **212**. In other examples, the width of the draw path can comprise a width of a slot from which glass is drawn from a slot draw process. In other embodiments, the width of the draw path can be defined by other features of the forming device that help define the resulting width of the glass ribbon. In further examples, the width of the draw path can be considered the width of the glass ribbon passing through the draw path at that location. For instance, the width of a transverse cross section of the draw path between the first lateral end **403a** and the second lateral end **403b** in **FIG. 4** can be equal to the width "**W**" of the glass ribbon at that location.

[0066] In further embodiments, the draw path may also be at least partially defined by the orientation of the forming device, forces that are applied to the glass ribbon, etc. As such, the draw path may be influenced during a draw process, for example, by applying force to the glass ribbon to alter the draw path of the glass ribbon during the drawing process. Such forces, may bend the glass ribbon and consequently bend the draw path of the glass ribbon as the glass ribbon is drawn from the forming device.

[0067] As shown in **FIGS. 3 and 4**, the draw path is represented by the dashed line **403** wherein the glass ribbon is shown being drawn through the draw path. As shown in **FIG. 4**, the draw path **403** may be positioned along the draw direction **207** of the draw apparatus **102**. As further illustrated in **FIG. 4**, the draw path **403** includes a transverse cross section taken perpendicular to the draw direction **207**. In some embodiments, the outer periphery of the draw path **403** can match the outer periphery of the illustrated glass ribbon **103**. Consequently, the draw path can extend in the draw direction **207** of the draw plane **211** of the draw apparatus **102**. Furthermore, by the transverse cross section taken perpendicular to the draw direction **207** shown in **FIG. 4**, the draw path **403** can include a first lateral end **403a** that may be coincident with the first lateral edge **103a** of the glass ribbon **103**. Furthermore, transverse cross section of the draw path **403** can include a second lateral end **403b** that may be coincident with the second lateral edge **103b** of the glass ribbon **103**. Still further, the transverse cross section of the draw path **403** can include a first side **405a** that can be coincident with a first major surface **104a** of the glass ribbon and a second side **405b** that can be coincident with a second major surface **104b** of the glass ribbon **103**. It will therefore be appreciated that, as illustrated, the transverse cross section of the draw path **403** can be substantially identical to a corresponding transverse cross-sectional profile of the glass ribbon **103** taken perpendicular to the draw direction **207**.

[0068] As further illustrated in **FIG. 4**, the draw apparatus **102** can further include a shroud **407** circumscribing the transverse cross section of the draw path **403**. The shroud can be formed from a wide range of insulating materials capable of withstanding the high temperature conditions associated with the glass manufacturing process. Furthermore, the shroud can include a wide range of shapes and sizes. For example, the shroud can include one or more walls that circumscribe the transverse cross section of the draw path **403** to define an interior area **409**. The draw path can extend along the draw plane **211** that divides the interior area **409** into a first portion **409a** bordered by the first major surface **104a** of the glass ribbon **103** and a second portion **409b** bordered by the second major surface **104b** of the glass ribbon **103**.

[0069] The illustrated shroud **407** includes four walls although one wall (e.g., an oblong or circular wall), two walls (e.g., D-shaped wall), three walls (e.g., triangular shaped wall), or five or more walls may be provided. As shown, the walls are substantially planar walls although different shaped walls may be provided. In some embodiments, the walls may comprise curvilinear walls (e.g., inwardly concave, inwardly convex, sinusoidal), a plurality of segments such as a stepped shape, peaks and valleys or other shape.

[0070] In the illustrated embodiment, the shroud **407** includes four walls that can optionally be planar walls including a first sidewall **411a** and a second sidewall **411b** positioned opposite the first sidewall **411a**. The first sidewall **411a** includes a first inner side surface **412a** that faces a second inner side surface **412b** of the second sidewall **411b**. In some embodiments, the first inner side surface **412a** may be parallel to the second inner side surface **412b**. A depth "**D**" of the interior area **409** of the shroud **407** is defined between the first inner side surface **412a** and the second inner side surface **412b**. A first end wall **413a** can join a first end of the first sidewall **411a** and a first end of the second sidewall **411b**. A second end wall **413b** can join a second end of the first sidewall **411a** and a second end of the second sidewall **411b**. The first end wall **413a** includes a first inner end surface **414a** that faces a second inner end surface **414b** of the second end wall **413b**. In some embodiments, the first inner end surface **414a** can be parallel to the second inner end surface **414b**. A width "**W2**" of the inner area **409** of the shroud **407** can be defined between the first inner end surface **414a** and the second inner end surface **414b**. In some embodiments, a ratio of "**W2"** with respect to **"D**" (i.e., **W2/D**) can be within a range of from about 0.4 to about 20, and in another embodiment, the ratio **W2/D** can be from about 1 to about 15, and in still another embodiment, the ratio **W2/D** can be from about 2.5 to about 10.

[0071] The width "**W2**" of the inner area **409** can be greater than a width "**W**" of the glass ribbon **103** being drawn along the draw path **403** within the interior area **409** of the shroud **407**. For example, as shown, the first end surface **414a** of the first end wall **413a** can be located laterally outside of the first lateral edge **103a** of the glass ribbon **103** and the first lateral end **403a** of the transverse cross section of the draw path **403** by a first lateral distance **415a**. Likewise, as further shown, the second end surface **414b** of the second end wall **413b** can be located laterally outside of the second lateral edge **103b** of the glass ribbon **103** and the second lateral end **403b** of the transverse cross section of the draw path **403** by a second lateral distance **415b**. For purposes of this application, unless otherwise noted, "laterally outside" is intended to mean a location that is not within: (1) a projection **437a** of the first major surface **104a** of the glass ribbon **103** in a first direction **439a** perpendicular to the first major surface **104a**, or (2) a projection **437b** of the second major surface **104b** of the glass ribbon **103** in a second direction **439b** perpendicular to the second major surface **104b**, wherein the second direction **439b** is opposite the first direction **439a**.

[0072] As shown, the first and second lateral distance **415a, 415b** can be measured in a direction perpendicular to the draw direction **207**. In some embodiments, the first lateral distance **415a** can be substantially equal to the second lateral distance **415b** although different lateral distances may be provided in further embodiments. As shown, "**W2**" is the sum of "**W**", **415a** and **415b**. In some embodiments, **415a** and **415b** may be equal to one another such that the center of "**W**" is coincident with the center of "**W2**". Although not shown, in further embodiments, the ratio of "**W2**" with respect to "**W**" (i.e., **W2/W**) can be within a range of from about 1.01 to about 2, an in another embodiment the ratio **W2/W** can be from about 1.03 to about 1.5, and in still another embodiment the ratio **W2/W** can be from about 1.06 to about 2 although other ratios may be provided in further examples. Relatively smaller lateral distances **415a, 415b** within these ranges can be desired to reduce material costs and the size of the shroud. In further examples, relatively larger lateral distances **415a, 415b** within these ranges can help position vacuum ports (described more fully below) further laterally outside of the first and second lateral end **403a, 403b** of the transverse cross section of the draw path **403** and/or further laterally outside the first and second lateral edge **103a, 103b** of the glass ribbon **103** to help improve the temperature difference uniformity across the width of the glass ribbon.

[0073] As further shown in **FIG. 4**, the glass ribbon **103** can therefore extend through the draw path **403** within the interior area **409** of the shroud **407**. As further illustrated, the first lateral edge **103a** of the glass ribbon **103** and the first lateral end **403a** of the transverse cross section of the draw path **403** can each face the first end surface **414a** of the first end wall **413a** of the shroud **407**. Likewise, the second lateral edge **103b** of the glass ribbon **103** and the second lateral end **403b** of the transverse cross section of the draw path **403** can each face the second end surface **414b** of the second end wall **413b** of the shroud **407**. Furthermore, the first major surface **104a** of the glass ribbon **103** and the first side **405a** of the transverse cross section of the draw path **403** can each face the first inner side surface **412a** of the first sidewall **411a** of the shroud **407**. Still further, the second major surface **104b** of the glass ribbon **103** and the second side **405b** of the transverse cross section of the draw path **403** can each face the second inner side surface **412b** of the second sidewall **411b** of the shroud **407**.

[0074] The draw apparatus of the present disclosure can further include at least one vacuum port. Any number of vacuum ports may be provided in accordance with aspects of the disclosure. The at least one vacuum port can be provided in any wall of the shroud **407** such as the first end wall **413a**, the second end wall **413b**, the first sidewall **411a** and/or the second sidewall **411b**. In such embodiment, the passage **421** can extend through the corresponding wall and the inner surface of the corresponding wall. For example, as shown, one or more vacuum ports **417a, 417b** may be provided in the first end wall **413a** of the shroud **407** and one or more vacuum ports **419a, 419b** may be provided in the second end wall **413b** of the shroud **407**.

[0075] As shown, the first end wall **413a** and associated vacuum ports **417a, 417b**, are located laterally outside of the first lateral end **403a** of the transverse cross section of the draw path **403** and being located laterally outside of the first lateral edge **103a** of the glass ribbon **103**. Indeed, the first end wall **413a** and associated vacuum ports **417a, 417b** are each located outside of the projection **437a** of the first major surface **104a** of the glass ribbon **103** in the first direction **439a** perpendicular to the first major surface **104a**. Furthermore, the first end wall **413a** and associated vacuum ports **417a**, **417b** are each located outside of the projection **437b** of the second major surface **104b** of the glass ribbon **103** in the second direction **439b** perpendicular to the second major surface **104b**, wherein the second direction **439b** is opposite the first direction **439a**.

[0076] Furthermore, the second end wall **413b** and associated vacuum ports **419a, 419b**, are located laterally outside of the second lateral end **403b** of the transverse cross section of the draw path **403** and being located laterally outside of the second lateral edge **103b** of the glass ribbon **103**. Indeed, the second end wall **413b** and associated vacuum ports **419a, 419b** are each located outside of the projection **437a** of the first major surface **104a** of the glass ribbon **103** in the first direction **439a** perpendicular to the first major surface **104a**. Furthermore, the second end wall **413b** and associated vacuum ports **419a, 419b** are each located outside of the projection **437b** of the second major surface **104b** of the glass ribbon **103** in the second direction **439b** perpendicular to the second major surface **104b**, wherein the second direction **439b** is opposite the first direction **439a**.

[0077] Although not show, in some embodiments, the first sidewall **411a** and/or the second sidewall **411b** may include one or more vacuum ports that are located laterally outside of the of the first lateral end **403a**/first lateral edge **103a** and laterally outside the second lateral end

403b/second lateral edge **103b**. For example, as shown in **FIG. 4**, the draw plane **211** can comprise a plane extending in the draw direction **207** and through the opposed edges **103a, 103b** of the glass ribbon **103**. An interior surface of the shroud **407** (e.g., the interior surfaces **412a, 412b, 414a, 414b**) circumscribes a length of the glass ribbon **103** along the draw direction **207**. A first area **441a** of the interior surface (e.g., a portion of the surface **412a**) is defined by the projection **437a** of the first major surface **104a** in the direction **439a** perpendicular to the plane **211**. A second area **441b** of the interior surface (e.g., a portion of the surface **412b**) is defined by the projection **437b** of the second major surface **104b** in the direction **439b** perpendicular to the plane **211**. The at least one vacuum port can include the passage **421** extending through the interior surface of the shroud **407** at a location outside of the first area **441a** and the second area **441b** of the interior surface. In the embodiment illustrated in **FIG. 4**, the location outside of the first area **441a** and the second area **441b** can be the entire first inner end surface **414a** of the first end wall **413a** and the entire second inner end surface **414b** of the second wall **413b**. Furthermore, as shown in **FIG. 4**, the location outside of the first area **441a** and the second area **441b** can be the end portions of the first inner side surface **412a** of the first sidewall **411a** and the second inner side surface **412b** of the second sidewall **411b**. As shown, the length of these end portions of the first and second inner side surface **412a, 412b** can have respective lengths equal to the first and second lateral distances **415a, 415b**.

[0078] As shown in **FIG. 4**, the at least one vacuum port consists of all of the vacuum ports of the draw apparatus **102**. Indeed, as shown, some embodiments may only include vacuum ports in the first end wall **413a** and/or the second end wall **413b** with no vacuum ports in the first sidewall **411a** or the second sidewall **411b**.

[0079] In some embodiments only the first end wall **413a** includes one or more vacuum ports with no other vacuum ports in the sidewalls **411a, 411b** or the second end wall **413b**. In further embodiments, only the second end wall **413b** includes one or more vacuum ports with no other vacuum ports in the sidewalls **411a, 411b** or the first end wall **413a**. In further examples, the at least one vacuum port can include at least one vacuum port (e.g., one or any number of vacuum ports) in the first end wall **413a** and at least one vacuum port (e,g., one or any number of vacuum ports) in the second end wall **413b** with no other vacuum ports in the sidewalls **411a, 411b**. Indeed, as illustrated the first end wall **413a** may include a first vacuum port **417a** and a second vacuum port **417b** and the second end wall **413b** may include a first vacuum port **419a**

and a second vacuum port **419b**. As further illustrated, in some embodiments, a plane (e.g., the draw plane **211**) of the draw path **403** may extend between the first vacuum port **417a** and the second vacuum port **417b** of the first end wall **413a**. Likewise, the plane (e.g., the draw plane **211**) of the draw path **403** may extend between the first vacuum port **419a** and the second vacuum port **419b** of the second end wall **413b**. Providing the plane positioned between the corresponding first and second vacuum ports allows for the vacuum ports to draw cooling fluid along the first portion **409a** of the interior area **409** to cool the first major surface **104a** of the glass ribbon and also draw cooling fluid along the second portion **409b** of the interior area **409** to cool the second major surface **104b** of the glass ribbon. Moreover, providing the plane (e.g., the draw plane **211**) of the draw path that bisects the distance between the corresponding pair of vacuum ports can promote equal cooling along the major surfaces of the glass ribbon.

[0080] Optionally, as shown, a pair of vacuum ports **417a, 419a** in the first and second end walls **413a, 413b** may be coaxially aligned with one another. Likewise, as also shown, another pair of vacuum ports **417b, 419b** may be coaxially aligned with one another. Providing coaxial alignment can allow for symmetrical cooling to facilitate equal drawing of cooling fluid through the corresponding first portion **409a** and second portion **409b** of the interior area **409** in use. Furthermore, pairs of vacuum ports may be offset from the draw plane **211**. For instance, as shown, the pair of vacuum ports **417a, 419a** may be aligned along a respective fluid intake axis **420** spaced a distance **423a** from the first major surface **104a** of the glass ribbon **103** (or corresponding to first side **405a** of the draw path **403**). Similarly, the pair of vacuum ports **417b, 419b** may be aligned along a fluid intake axis **422** spaced a distance **423b** from the second major surface **104b** of the glass ribbon **103** (corresponding to the second side **405b** of the draw path **403**). The distances **423a, 423b** may be different from one another. However, in some embodiments, the distances **423a, 423b** may be substantially equal to promote equal cooling on each major surface of the glass ribbon **103**. For purposes of this disclosure, the fluid intake axis means an axis extending through the opening of the vacuum port extending in a direction that is the resultant vector of the glass flowing through the opening of the vacuum port when a vacuum is applied to the vacuum port to draw gas into the vacuum port.

[0081] Furthermore, as shown, the fluid intake axis **420, 422** of any of the vacuum ports may be substantially parallel to the first major surface **104a** and the second major surface **104b** of the glass ribbon **103**. Providing axes that are parallel to the major surfaces of the glass ribbon can help develop a desired fluid flow profile that promotes relatively even cooling along the glass ribbon when compared to other configurations.

[0082] Each vacuum port may have a fluid flow adjustment device associated with the vacuum port to allow fine tuning of the fluid flow rate through the vacuum port relative to the other vacuum ports. For instance, as shown in **FIG. 4**, each vacuum port may include an adjustment device **425**. As shown in **FIG. 5**, in one embodiment, the adjustment device **425** may comprise a restriction plate **501** with a plurality of differently sized openings **503a, 503b, 503c**. In the illustrated position, a smaller opening **503a** is aligned with the passage to restrict flow. In order to reduce the flow restriction, the restriction plate may be moved in direction **505** until one of the larger sized openings **503b, 503c** is aligned with the passage to provide the desired flow restriction.

[0083] With further reference to **FIG. 4**, a common coupling conduit **427a** may be used to provide a common fluid connection between a vacuum source **429** and a pair of the vacuum ports **417a, 417b**. The vacuum source **429** can comprise a vacuum chamber, a blower, pump, fan, or other vacuum device. The common coupling conduit **427a** may form a T-joint with a first conduit **431a** that is connected to the fluid source **429** by a fluid source conduit **433**. Likewise, another common coupling conduit **427b** may be used to provide a common fluid connection between the vacuum source **429** and a pair of the vacuum ports **419a, 419b**. Indeed, the common coupling conduit **427b** may form a T-joint with a second conduit **431b** that is connected to the fluid source **429** by a fluid source conduit **433**. Providing the common coupling conduits **427a, 427b** can simplify the design, where relative fluid intake from the vacuum ports **417a, 417b** and the vacuum ports **419a, 419b** can be adjusted by way of the adjustment devices **425**. Likewise, relative fluid intake from the vacuum ports **417a, 417b** associated with the first end wall **413a** can be adjusted with a first side valve **435a**. Furthermore, relative fluid intake from the vacuum ports **419a, 419b** associated with the second end wall **413b** may be adjusted with the second side valve **435b**.

[0084] In an alternative arrangement (not illustrated), vacuum ports **417a, 419a** may be connected together with a common coupling conduit and the other vacuum ports **417b, 419b** may be connected together with another common coupling. In such an embodiment a first valve may be used to adjust the fluid intake from the vacuum ports **417a, 419a** while a second valve may be used to adjust the fluid intake from the vacuum ports **417b, 419b**.

[0085] Referring to **FIG. 6**, it will be appreciated that a plurality of ports may be provided at alternate and/or a plurality of elevations within the shroud **407**. For instance, the schematic cross section of **FIG. 6**, shows the one embodiment of a convection cooling apparatus that includes a plurality of elevations. Indeed, in the illustrated embodiment, a first pair of the previously described first and second vacuum ports **419a, 419b** can optionally be provided in the second end wall **413b** at a first elevation **601**. Furthermore, as shown, a second pair of the previously described first and second vacuum ports **419a, 419b** can also be provided in the second end wall **413b** at a higher elevation **603**. Although not shown, similar or identical vacuum ports may be provided in the first end wall **413a**. Providing the vacuum ports at different elevations can help control the cooling rate at various elevational locations of the glass ribbon along the draw direction **207**.

[0086] Methods of producing the glass ribbon **103** will now be described. Referring to **FIGS. 1 and 2**, as mentioned previously, the method can include drawing the glass ribbon **103** in the draw direction **207**. As shown in **FIG. 1**, the glass ribbon **103** can be drawn with a width "**W**" between opposed edges **103a, 103b** of the glass ribbon. Further, as shown in **FIG. 2**, the drawn glass ribbon **103** includes the first major surface **104a** and the second major surface **104b** that extend between the opposed edges **103a, 103b** of the glass ribbon **103**. As mentioned previously, many alternative draw apparatus may be provided to draw the glass ribbon **103**. For instance, in the previously described embodiment, the glass ribbon may be optionally fusion drawn from the root **209** of the forming wedge **201** discussed above.

[0087] The method can further include applying a vacuum only to at least one vacuum port located laterally outside of at least one of the opposed edges of the glass ribbon. As such, the method can apply a vacuum to one or any plurality of vacuum ports that are all located laterally outside of at least one of the opposed edges of the glass ribbon without applying a vacuum to any vacuum port located laterally inside of the opposed edges of the glass ribbon. Throughout the application, vacuum can refer to pressures that are lower than the atmosphere surrounding the shroud **407**. Consequently, placing the vacuum ports in communication with a vacuum source can likewise result in lowering the pressure within the interior area **409** of the shroud **407** to a pressure lower than the atmosphere surrounding the shroud **407**.

[0088] In some embodiments, the at least one of the plurality of vacuum ports may be positioned in one or both of the first sidewall **411a** and the second sidewall **411b**. In such examples, all of the vacuum ports are located laterally outside of the at least one of the opposed edges of the glass ribbon. For instance, in one embodiment, a passage **421** of a vacuum port may extend through the first inner side surface **412a** of the first sidewall **411a** at a location outside of the first area **441a**. In another embodiment, a passage **421** of a vacuum port may extend through the second inner side surface **412b** of the second sidewall **411b** at a location outside of the second area **441b**.

[0089] In further embodiments, the plurality of vacuum ports may be positioned in one of the first sidewall **411a** and the second sidewall **411b** in addition to one of the first end wall **413a** and the second end wall **413b**. In further embodiments, the plurality of vacuum ports may only be positioned in the first end wall **413a** and/or the second end wall **413b**. In such examples, each vacuum port is located laterally outside of the at least one of the opposed edges of the glass ribbon. In one embodiment, as shown in **FIG. 4**, the first vacuum port **417a** and the second vacuum port **417b** each include the passage **421** passing through the first end wall **413a** with an opening in the first inner end surface **414a** that is located laterally outside of the first lateral edge **103a** of the glass ribbon **103** by the first lateral distance **415a**. Likewise, the first vacuum port **419a** and the second vacuum port **419b** each include the passage **421** passing through the second end wall **413b** with an opening in the second inner end surface **414b** that is located laterally outside of the second lateral edge **103b** of the glass ribbon **103** by the second lateral distance **415b**.

[0090] Methods of the disclosure can promote convection cooling of the glass ribbon as it is drawn through the shroud **407**. In one embodiment, referring to **FIG. 6**, the freshly drawn glass ribbon **103** may be relatively hot when being drawn through the shroud **407**. The glass ribbon **103** may therefore heat the air or other gas within the interior area **409** of the shroud **407**. The heating the gas within the interior area **409** of the shroud **407** reduces the density of the gas, such that the density of the gas within the interior area **409** of the shroud **407** is less than the density of the lower-temperature gas outside of the shroud **407**. Consequently, the heated gas with relatively less density within the interior area **409** of the shroud **407** rises upwardly in direction **608** through the interior **409** of the shroud **407** due to the buoyancy of the heated gas relative to the cooler gas located outside of the shroud **407**. In some examples, a directional component or the resultant vector of the direction **608** can be opposite with respect to the draw direction **207**. In some examples, the draw direction may also include a directional component or a resultant vector in the direction of gravity. As such, the shroud **407** can act as a chimney wherein gas **605a, 605b** may be drawn through a lower opening **607a** of the interior area **409** and portions of the gas **606a, 606b** being subsequently released through the upper opening **607b**.

[0091] In the illustrated embodiment, at least a portion of the gas **605a** can travel along an upstream path **609a**, an intermediate path **611a** and a downstream path **613a** within the first portion **409a** of the interior area **409** to cool the first major surface **104a** of the glass ribbon **103**. As further illustrated, at least a portion of the gas **605b** can travel along an upstream path **609b**, an intermediate path **611b** and a downstream path **613b** within the second portion **409b** of the interior area **409** to cool the second major surface **104b** of the glass ribbon **103**. As such, the gas traveling upward through the corresponding upstream path **609a, 609b**, the corresponding intermediate path **611a, 611b**, and the corresponding downstream path **613a, 613b** prior to exiting the upper opening **607b** of the interior area **409** can provide convection cooling of the glass ribbon as the glass ribbon is being drawn through the interior **409** of the shroud **407**.

[0092] In some embodiments, there may be a desire to augment the convection cooling of the glass ribbon. For instance, increasing the convection cooling rate of the glass ribbon can allow for faster draw rates of the glass ribbon through the shroud **407** without needing to increase the height of the shroud **407**. As such, a shroud **407** may be maintained at the same height or may even be provided at a reduced height to avoid material costs involved with increasing the height of the shroud.

[0093] To supplement the convection cooling of the glass ribbon **103**, the method can include the step of applying a vacuum to one or any plurality of the vacuum ports located laterally outside of the at least one of the opposed edges **103a, 103b** of the glass ribbon **103** as described above. In one embodiment, the vacuum source **429** may draw fluid (e.g., air or other gas) through the fluid source conduit **433** that draws fluid through the first conduit **431a** and the second conduit **431b** at a proportional rate adjusted by the first side valve **435a** and the second side valve **435b**.

[0094] With reference to the first conduit **431a**, fluid can then be drawn through the common coupling conduit **427a** where fluid can then be drawn through the passage **421** of the first vacuum port **417a** and the second vacuum port **417b** at a proportional rate adjusted by the adjustment device **425** associated with each of the first vacuum port **417a** and the second vacuum port **417b**. Likewise, with reference to the second conduit **431b**, fluid can also be drawn through the common coupling conduit **427b** where fluid can then be drawn through the passage **421** of the first vacuum port **419a** and the second vacuum port **419b** at a proportional rate adjusted by the adjustment device **425** associated with each of the first vacuum port **419a** and the second vacuum port **419b**.

[0095] As described above, applying the vacuum to the at least one vacuum port (e.g., **417a, 417b, 419a, 419b**) as discussed in the example embodiments above can promote convection cooling of the glass ribbon, such as enhance existing convection cooling of the glass ribbon, with a cooling fluid flow generated at least partially by the vacuum being applied to the at least one vacuum port. In one embodiment, applying the vacuum can increase convection cooling of the glass ribbon above and beyond what is achieved by convection cooling driven by the chimney effect discussed above.

[0096] In one embodiment, drawing gas through the first vacuum port **417a** of the first end wall **413a** at the first elevation **601** and drawing gas through the first vacuum port **419a** of the second end wall **413b** at the first elevation **601** can cause a downstream portion of the gas traveling along the upstream path **609a** of the first portion **409a** of the interior area **409** to travel along a transverse path **610a** and into the respective first vacuum port **417a, 419a** at the first elevation **601**. As such, applying vacuum to the first vacuum ports **417a, 419a** at the first elevation **601** can increase flow rate of the fluid along the upstream path **609a** and consequently increase the convection cooling of the glass ribbon along the upstream path **609a**. Likewise, drawing gas through the second vacuum port **417b** of the first end wall **413a** at the first elevation **601** and drawing gas through the second vacuum port **419b** of the second end wall **413b** at the first elevation **601** can cause a downstream portion of the gas traveling along the upstream path **609b** of the second portion **409b** of the interior area **409** to travel along a transverse path **610b** and into the respective second vacuum port **417b, 419b** at the first elevation **601**. As such, applying vacuum to the second vacuum ports **417b, 419b** at the first elevation **601** can increase flow rate of the fluid along the upstream path **609b** and consequently increase the convection cooling of the glass ribbon along the upstream path **609b**.

[0097] In another embodiment, drawing gas through the first vacuum port **417a** of the first end wall **413a** at the second elevation **603** and drawing gas through the first vacuum port **419a** of the second end wall **413b** at the second elevation **603** can cause a downstream portion of the gas traveling along the intermediate path **611a** of the first portion **409a** of the interior area

409 to travel along a transverse path **612a** and into the respective first vacuum port **417a, 419a** at the second elevation **603**. As such, applying vacuum to the first vacuum ports **417a, 419a** at the second elevation **603** can increase flow rate of the fluid along the upstream path **609a** and the intermediate path **611a** and consequently increase the convection cooling of the glass ribbon along the upstream path **609a** and the intermediate path **611a**. Likewise, drawing gas through the second vacuum port **417b** of the first end wall **413a** at the second elevation **603** and drawing gas through the second vacuum port **419b** of the second end wall **413b** at the second elevation **603** can cause a downstream portion of the gas traveling along the intermediate path **611b** of the second portion **409b** of the interior area **409** to travel along a transverse path **612b** and into the respective second vacuum port **417b, 419b** at the second elevation **603**. As such, applying vacuum to the second vacuum ports **417b, 419b** at the second elevation **603** can increase flow rate of the fluid along the upstream path **609b** and the intermediate path **611b** and consequently increase the convection cooling of the glass ribbon along the upstream path **609b** and the intermediate path **611b**.

[0098] Any of the embodiment of the disclosure can include contacting the first major surface **104a** and/or the second major surface **104b** of the glass ribbon **103** with the cooling fluid flow. Providing direct contact of the fluid with the glass ribbon can increase the cooling convection of the glass ribbon without relying on conduction or radiation heat transfer that may be incorporated in heat transfer panels (not shown) in further examples of the disclosure.

[0099] In any of the embodiments of the disclosure, applying the vacuum may promote an upstream portion of the cooling fluid flow to travel along an upstream flow direction that is substantially opposite to the draw direction. In addition or alternatively, the vacuum can promote a downstream portion of the cooling fluid flow to travel along a downstream flow direction that extends across the draw direction. For instance, with reference to **FIGS. 3 and 6**, the upstream paths **609a, 609b** illustrate that cooling fluid flow can travel along an upstream flow direction **609** that is substantially opposite the draw direction **207**. The vacuum can also promote a downstream portion of the cooling fluid to travel along a transverse path **610a, 610b** that is transverse to the draw direction **207** by extending across, such as perpendicular, to the draw direction **207**. In a similar fashion the vacuum can also promote fluid flowing along intermediate paths **611a, 611b** (that are upstream relative to the transverse paths **612a, 612b**), to travel along the upstream flow direction **608** that is substantially opposite the draw direction **207**.

Further, the vacuum can also promote cooling fluid to travel along a transverse path **612a, 612b** that is transverse to the draw direction **207** by extend across, such as perpendicular, to the draw direction **207**.

[00100] As such, applying vacuum to the vacuum ports can enhance convective cooling of the glass ribbon traveling through the shroud **407**. Moreover, locating the vacuum ports laterally outside of the at least one of the opposed edges of the glass ribbon can promote enhanced convection cooling at greater flow rates while maintaining a desirable cooling profile across the width of the glass ribbon. In some embodiments, the combined mass flow rate of the air can be related to the mass flow rate of the glass ribbon being drawn. For example, the glass ribbon may be drawn at a glass ribbon mass flow rate "**Mglass**" and the cooling fluid flow may be drawn through all of the at least one vacuum port at a combined mass flow rate "**Mair**". For purposes of the disclosure, a combined cooling fluid flow rate is the flow rate through each of the fluid ports added together. For example, if there are 8 total vacuum ports with each vacuum port is drawing cooling fluid at a rate of "**R**", the mass flow rate of the cooling fluid flow would be 8**R** (i.e., 8 x "R" = 8**R**). In some embodiments, the ratio "**Mair"** with respect to "**Mglass**" (i.e., **Mair/Mglass**) is within a range of from about 0.036 to about 7.143. In another embodiment, the ratio "**Mair**" with respect to "**Mglass**" (i.e., **Mair/Mglass**) is within a range of from about 0.357 to about 2.143. In another embodiment, the ratio "**Mair**" with respect to "**Mglass**" (i.e., **Mair/Mglass**) is within a range of from about 0.357 to about 1.071.

[00101] **FIGS. 10-14** demonstrate simulated test results associated with cooling the glass ribbon with a cooling apparatus with all of the vacuum ports located laterally outside of the at least one of the opposed edges of the glass ribbon. Throughout **FIGS. 10-14**, the vertical axis ("y" axis) represents the distance, in inches, below the root of the forming wedge while the horizontal axis ("x" axis) represents the distance, in inches, from the glass ribbon center. **FIGS. 10-14** are simulations at various exemplary combined flow rates showing desirable results. Specifically, each of **FIGS. 10-14** is a simulation showing changes in a temperature difference between: (1) natural cooling without use of the vacuum ports of the present application; and (2) forced cooling using the vacuum port design of the present application at various combined flow rates.

[00102] **FIG. 10** is a simulation with a ratio "**Mair"** with respect to "**Mglass"** (i.e., **Mair/Mglass**) of 0.036. **FIG. 10** demonstrates desirable results, at least from about 114.3

centimeters (45 inches) to about 165.1 centimeters (65 inches) below the root of the forming wedge. Indeed, as shown, temperature difference contours **1001a-c** extend substantially along relatively uniform pressure differential paths through a central portion [e.g., ± 50.8 centimeters (20 inches) from the glass ribbon center] of the width of the glass ribbon, indicating the temperature difference remains substantially constant across the width of the central portion of the glass ribbon.

[00103] **FIG. 11** is a simulation with a ratio "**Mair**" with respect to "**Mglass**" (i.e., **Mair/Mglass**) of 0.357. **FIG. 11** demonstrates desirable results, at least from about 101.6 centimeters (40 inches) to about 203.2 centimeters (80 inches) below the root of the forming wedge. Indeed, as shown, temperature difference contours **1101a-e** extend substantially along relatively uniform pressure differential paths through a central portion [e.g., ± 50.8 centimeters (20 inches) from the glass ribbon center] of the width of the glass ribbon, indicating the temperature difference remains substantially constant across the width of the central portion of the glass ribbon.

[00104] **FIG. 12** is a simulation with a ratio "**Mair**" with respect to "**Mglass**" (i.e., **Mair/Mglass**) of 1.071. **FIG. 12** demonstrates desirable results, at least from about 88.9 centimeters (35 inches) to about 203.2 centimeters (80 inches) below the root of the forming wedge. Indeed, as shown, temperature difference contours **1201a-k** extend substantially along relatively uniform pressure differential paths through a central portion [e.g., ± 50.8 centimeters (20 inches) from the glass ribbon center] of the width of the glass ribbon, indicating the temperature difference remains substantially constant across the width of the central portion of the glass ribbon.

[00105] **FIG. 13** is a simulation with a ratio "**Mair**" with respect to "**Mglass**" (i.e., **Mair/Mglass**) of 2.143. **FIG. 13** demonstrates desirable results, at least from about 101.6 centimeters (40 inches) to about 203.2 centimeters (80 inches) below the root of the forming wedge. Indeed, as shown, temperature difference contours **1301a-h** extend substantially along relatively uniform pressure differential paths through a central portion [e.g., ± 50.8 centimeters (20 inches) from the glass ribbon center] of the width of the glass ribbon, indicating the temperature difference remains substantially constant across the width of the central portion of the glass ribbon.

[00106] **FIG. 14** is a simulation with a ratio "**Mair**" with respect to "**Mglass**" (i.e., **Mair/Mglass**) of 7.143. **FIG. 14** demonstrates desirable results, at least from about 152.4 centimeters (60 inches) to about 203.2 centimeters (80 inches) below the root of the forming wedge. Indeed, as shown, temperature difference contours **1401a-e** extend substantially along relatively uniform pressure differential paths through a central portion [e.g., ± 50.8 centimeters (20 inches) from the glass ribbon center] of the width of the glass ribbon, indicating the temperature difference remains substantially constant across the width of the central portion of the glass ribbon.

[00107] It will be apparent to those skilled in the art that various modifications and variations can be made to the described embodiments without departing from the spirit and scope of the claimed invention. Thus, it is intended that the present claimed invention cover the modifications and variations of the embodiments described herein provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. A method of producing a glass ribbon including:

drawing a glass ribbon along a draw direction, wherein the glass ribbon includes a first major surface and a second major surface, and each of the first major surface and the second major surface extending between opposed edges of the glass ribbon; and

applying a vacuum only to at least one vacuum port located laterally outside of at least one of the opposed edges of the glass ribbon to promote convection cooling of the glass ribbon with a cooling fluid flow generated at least partially by the vacuum being applied to the at least one vacuum port.

2. The method of claim 1, further including contacting at least one of the first major surface and the second major surface of the glass ribbon with the cooling fluid flow.

3. The method of claim 1, wherein applying the vacuum promotes an upstream portion of the cooling fluid flow to travel along an upstream flow direction that is substantially opposite to the draw direction.

4. The method of claim 3, wherein applying the vacuum promotes a downstream portion of the cooling fluid flow to travel along a downstream flow direction that extends across the draw direction.

5. The method of claim 1, wherein applying the vacuum promotes a downstream portion of the cooling fluid flow to travel along a downstream flow direction that extends across the draw direction.

6. The method of claim 1, further including drawing the glass ribbon at a glass ribbon mass flow rate (Mglass) and drawing the cooling fluid flow through all of the at least one vacuum port at a combined mass flow rate (Mair), wherein a ratio of Mair with respect to Mglass is within a range of from about 0.036 to about 7.143.

7. The method of claim 6, wherein the ratio of Mair with respect to Mglass is within a range of from about 0.357 to about 2.143.

8. The method of claim 7, wherein the ratio of Mair with respect to Mglass is within a range of from about 0.357 to about 1.071.

9. The method of claim 1, wherein the glass ribbon is drawn by fusion drawing the glass ribbon from a root of a forming wedge.

10. A draw apparatus for producing a glass ribbon, the draw apparatus comprising:

a draw path for a glass ribbon, the draw path being defined by the draw apparatus and positioned along a draw direction of the draw apparatus, and the draw path including a transverse cross section taken perpendicular to the draw direction;

a shroud circumscribing the transverse cross section of the draw path; and

at least one vacuum port including a passage extending through one of a first end wall and a second end wall of the shroud, a first lateral end of the transverse cross section of the draw path facing the first end wall of the shroud, a second lateral end of the transverse cross section of the draw path facing the second end wall of the shroud, the first end wall of the shroud being located laterally outside of the first lateral end of the transverse cross section of the draw path, and the second end wall of the shroud being located laterally outside of the second lateral end of the transverse cross section of the draw path.

11. The draw apparatus of claim 10, wherein the at least one vacuum port consists of all of the vacuum ports of the draw apparatus.

12. The draw apparatus of claim 10, wherein the at least one vacuum port includes at least one vacuum port in the first end wall and at least one vacuum port in the second end wall.

13. The draw apparatus of claim 10, wherein the at least one vacuum port includes two vacuum ports in the first end wall.

14. The draw apparatus of claim 13, wherein a plane passing through the first lateral end and the second lateral end extends between the two vacuum ports.

15. The draw apparatus of claim 13, wherein the at least one vacuum port further includes two additional vacuum ports in the second end wall.

16. The draw apparatus of claim 15, wherein a plane passing through the first lateral end and the second lateral end extends between the two vacuum ports in the first end wall and the two additional vacuum ports in the second end wall.

17. A glass apparatus including a glass ribbon and the draw apparatus of claim 10, the glass apparatus comprising:

the glass ribbon including a first major surface and a second major surface, and each of the first major surface and the second major surface extending between opposed edges of the glass ribbon;

the glass ribbon extending through the draw path, a first edge of the opposed edges of the glass ribbon facing the first end wall of the shroud, a second edge of the opposed edges of the glass ribbon facing the second end wall of the shroud, the first major surface of the glass ribbon facing a first sidewall of the shroud and the second major surface of the glass ribbon facing a second sidewall of the shroud.

18. The glass apparatus of claim 17, wherein neither the first sidewall of the shroud nor the second sidewall of the shroud includes a vacuum port.

19. The glass apparatus of claim 17, wherein a fluid intake axis of the at least one vacuum port is substantially parallel to the first major surface and the second major surface of the glass ribbon.

20. The glass apparatus of claim 17, wherein the glass ribbon extends along a draw plane of the draw path, wherein the at least one vacuum port is offset from the draw plane.

21. A glass apparatus comprising:

a glass ribbon extending along a draw direction, the glass ribbon including a first major surface and a second major surface, each of the first major surface and the second major surface extending between opposed edges of the glass ribbon, and a plane of the glass ribbon extends in the draw direction and through the opposed edges of the glass ribbon;

a shroud including an interior surface circumscribing a length of the glass ribbon extending along the draw direction, a first area of the interior surface defined by a projection of the first major surface in a first direction perpendicular to the plane, a second area of the interior surface defined by a projection of the second major surface in a second direction perpendicular to the plane and opposite the first direction; and

at least one vacuum port including a passage extending through the interior surface of the shroud at a location outside of the first and second area of the interior surface.

22. The glass apparatus of claim 21, wherein the at least one vacuum port consists of all of the vacuum ports of the draw apparatus.

23. The glass apparatus of claim 21, wherein the shroud includes a first sidewall including the first area of the interior surface, a second sidewall including the second area of the interior surface, a first end wall joining a first end of the first sidewall and a first end of the second sidewall, and a second end wall joining a second end of the first sidewall and a second end of the second sidewall.

24. The glass apparatus of claim 23, wherein the at least one vacuum port is located in at least one of the first end wall, the second end wall, the first sidewall and the second sidewall.

25. The glass apparatus of claim 24, wherein the at least one vacuum port is located in at least one of the first end wall and the second end wall.

26. The glass apparatus of claim 25, wherein the at least one vacuum port includes two vacuum ports in the first end wall.

27. The glass apparatus of claim 26, wherein the plane passes between the two vacuum ports in the first sidewall.

28. The glass apparatus of claim 27, wherein the at least one vacuum port further includes two additional vacuum ports in the second end wall.

29. The glass apparatus of claim 28, wherein the plane passes between the two vacuum ports in the first end wall and the two additional vacuum ports in the second end wall.

30. The glass apparatus of claim 23, wherein neither the first sidewall of the shroud nor the second sidewall of the shroud includes a vacuum port.

31. The glass apparatus of claim 21, wherein a fluid intake axis of the at least one vacuum port is substantially parallel to the first major surface and the second major surface of the glass ribbon.

32. The glass apparatus of claim 21, wherein the at least one vacuum port is offset from the plane.

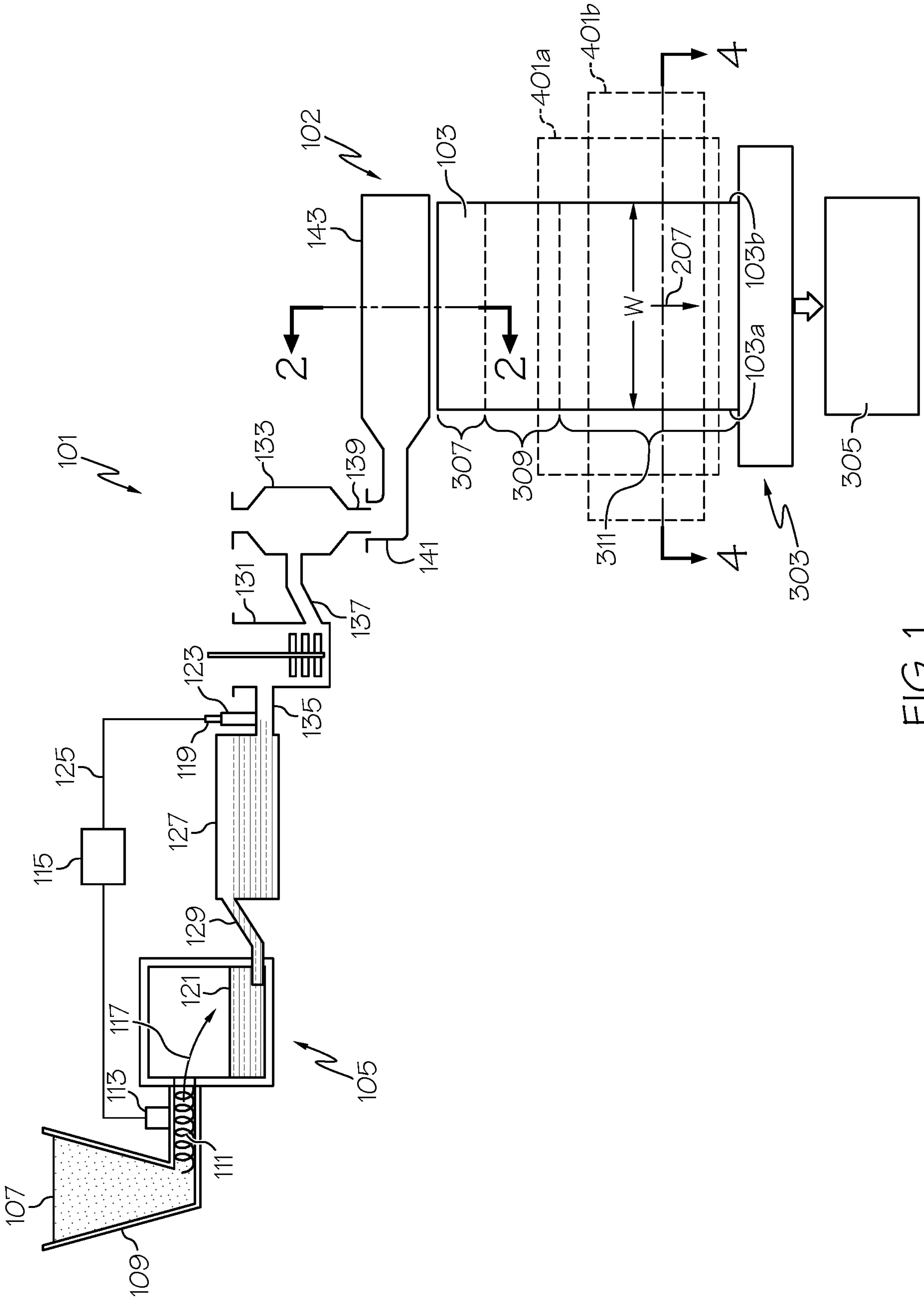
101
102
103
103a
103b
105
107
109
111
113
115
117
119
121
123
125
127
129
131
133
135
137
139
141
143
2
2
4
4
207
W
303
305
307
309
311
401a
401b

FIG. 1

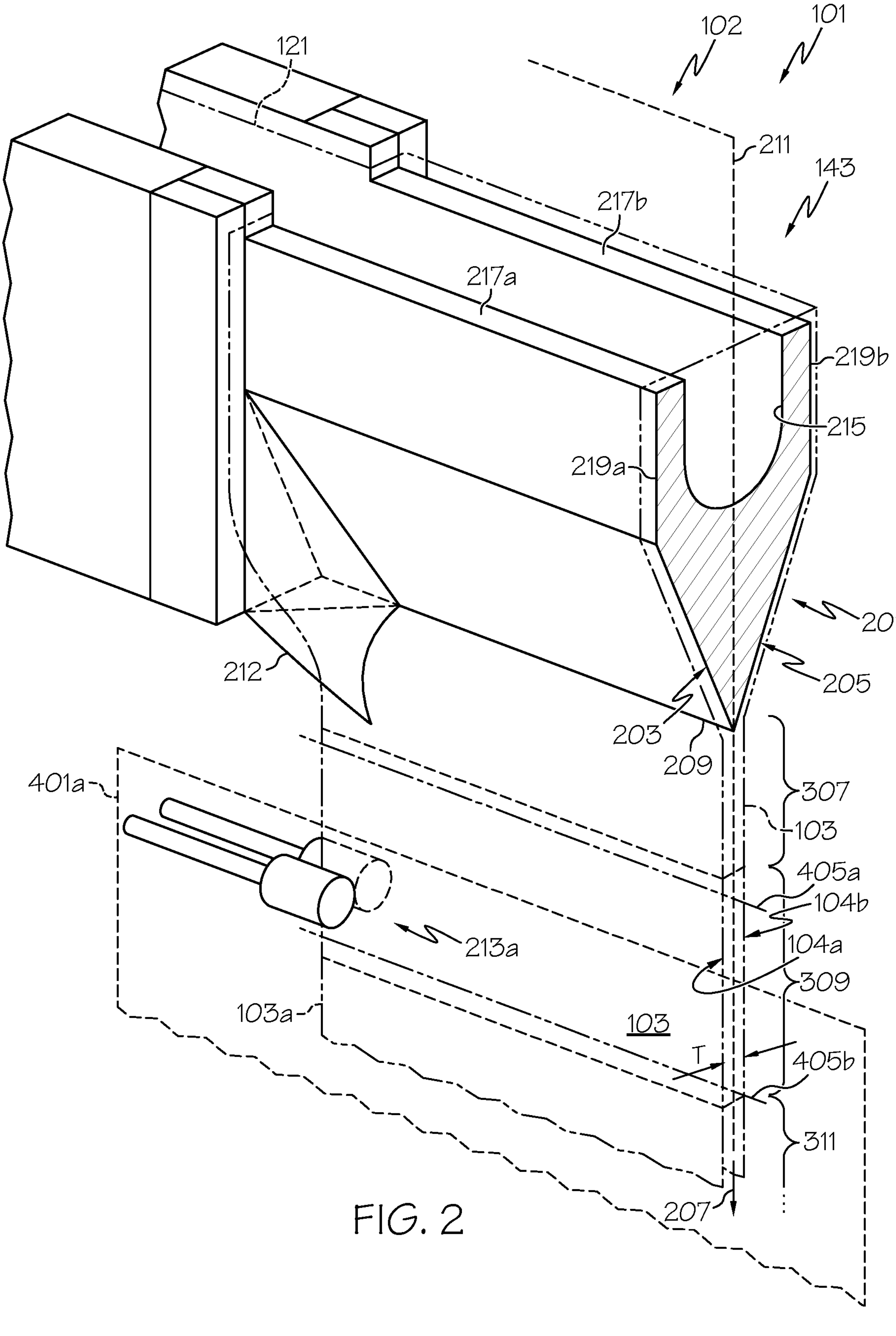
102
101
121
211
143
217b
217a
219b
215
219a
201
205
212
203
209
307
401a
103
405a
104b
213a
104a
309
103a
103
T
405b
311
207

FIG. 2

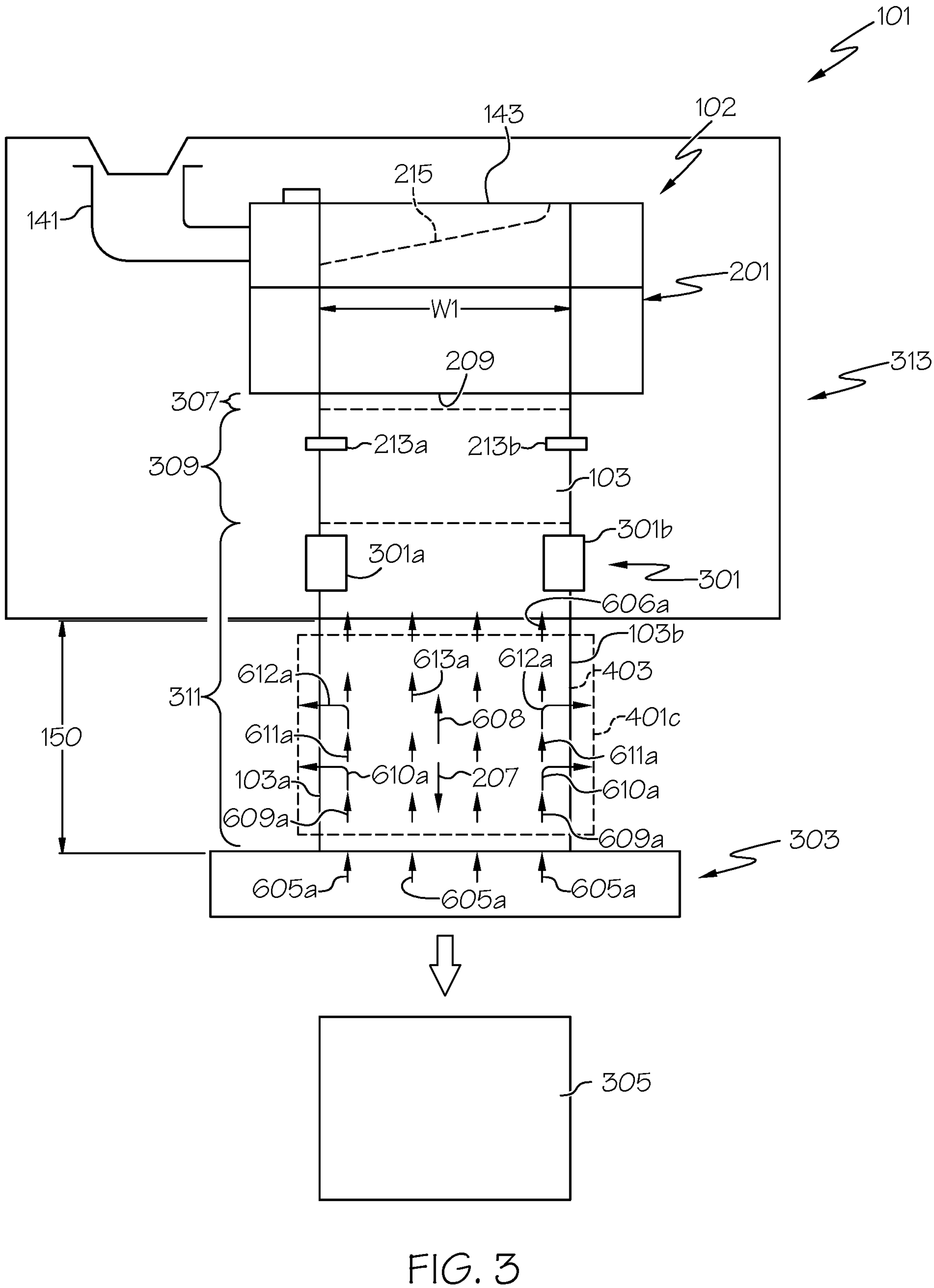
101
102
143
215
141
201
W1
209
313
307
309
213a
213b
103
301a
301b
301
606a
103b
612a
613a
612a
403
311
401c
608
150
611a
611a
103a
610a
207
610a
609a
609a
303
605a
605a
605a
305

FIG. 3

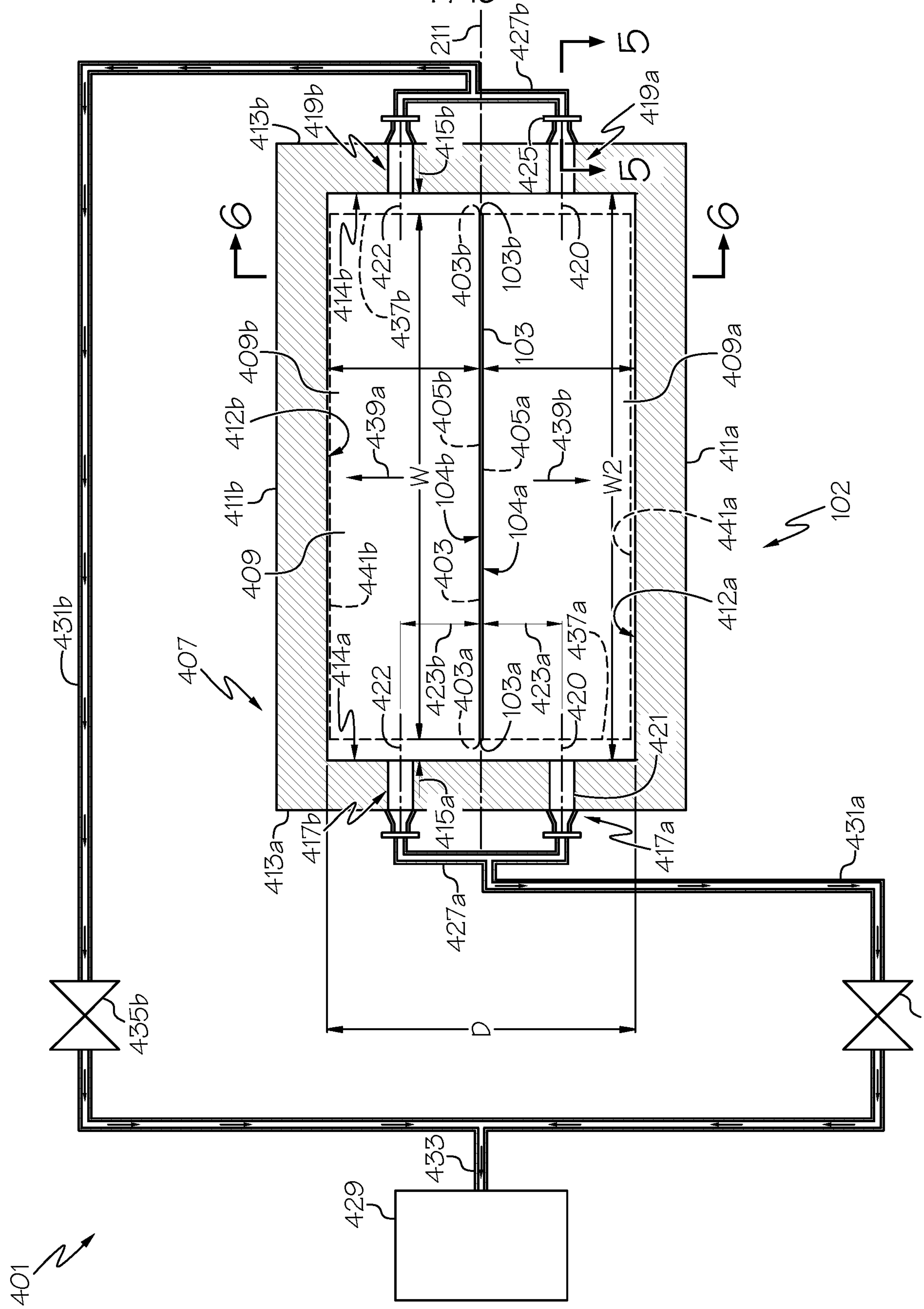
211
427b
5
419a
425
5
413b
419b
415b
6
6
422
414b
437b
403b
103b
420
103
409b
409a
412b
439a
405b
405a
439b
411b
W
104b
104a
W2
411a
441a
102
409
441b
403
412a
407
414a
423b
403a
103a
423a
437a
422
420
421
413a
417b
415a
417a
431a
427a
431b
D
435b
435a
433
429
401

FIG. 4

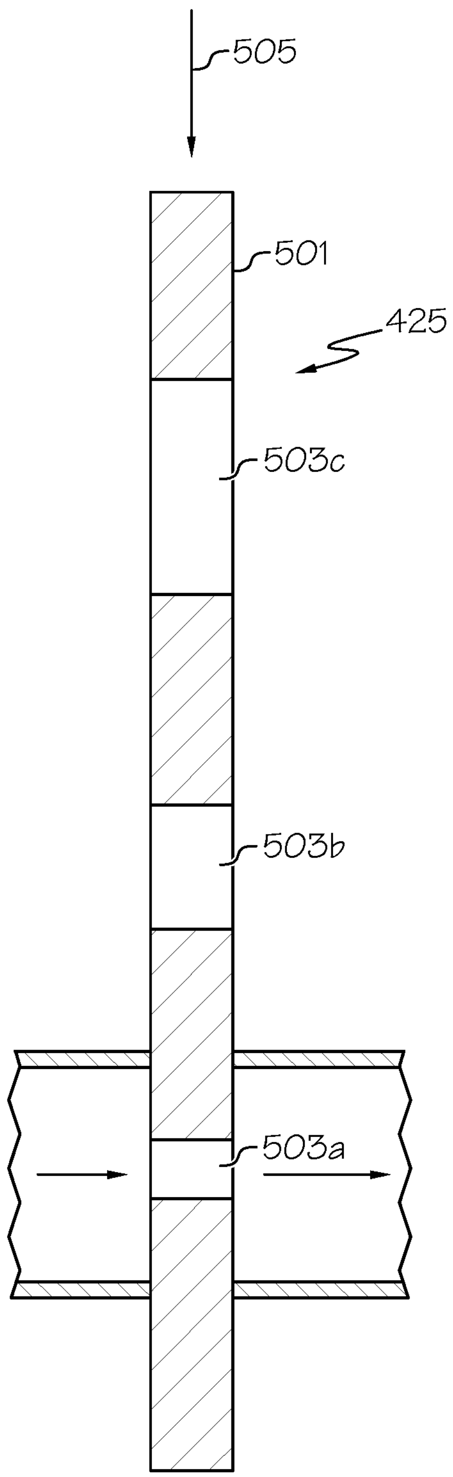

FIG. 5

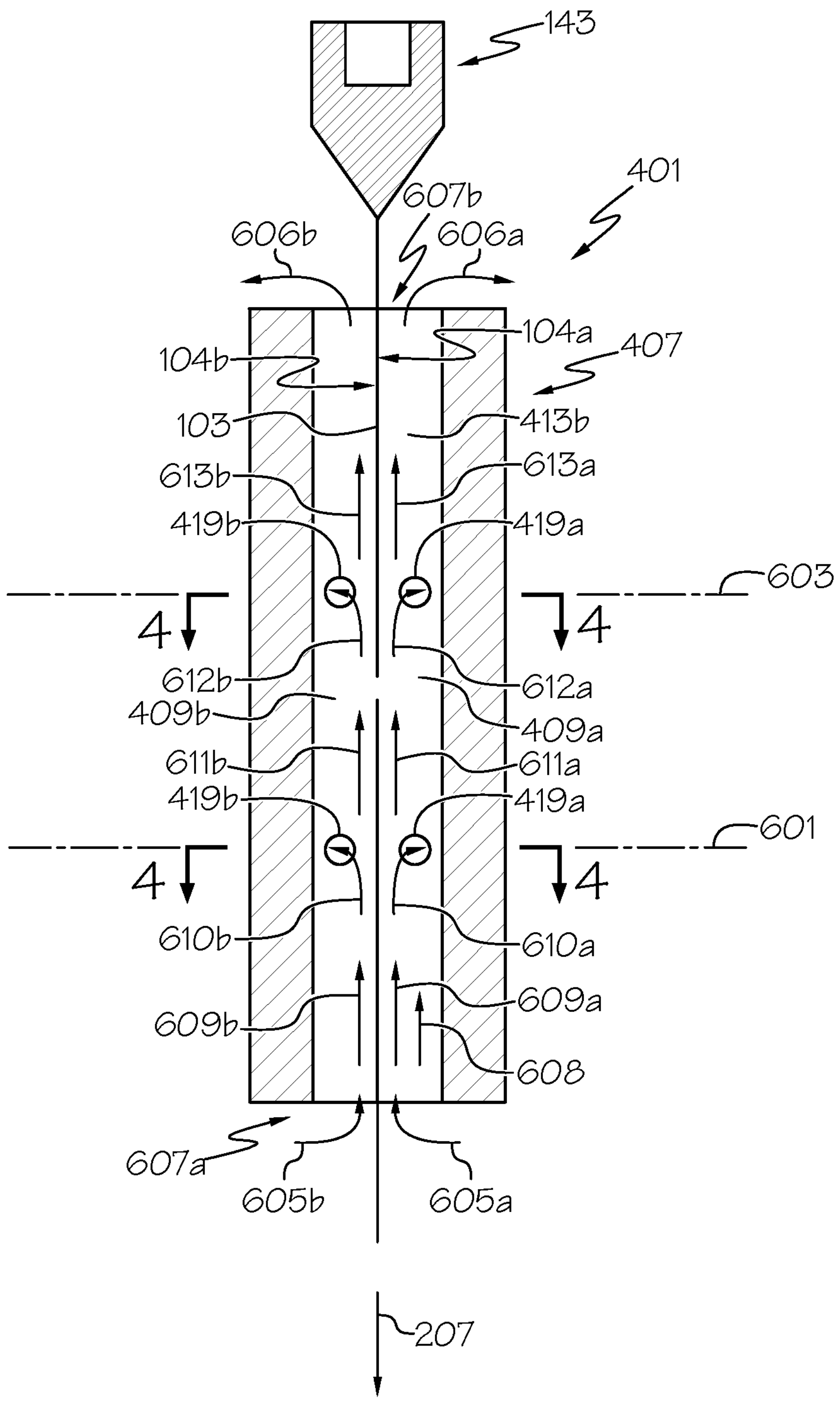
143
401
607b
606b
606a
104a
104b
407
103
413b
613b
613a
419b
419a
603
4
4
612b
612a
409b
409a
611b
611a
419b
419a
601
4
4
610b
610a
609a
609b
608
607a
605b
605a
207

FIG. 6

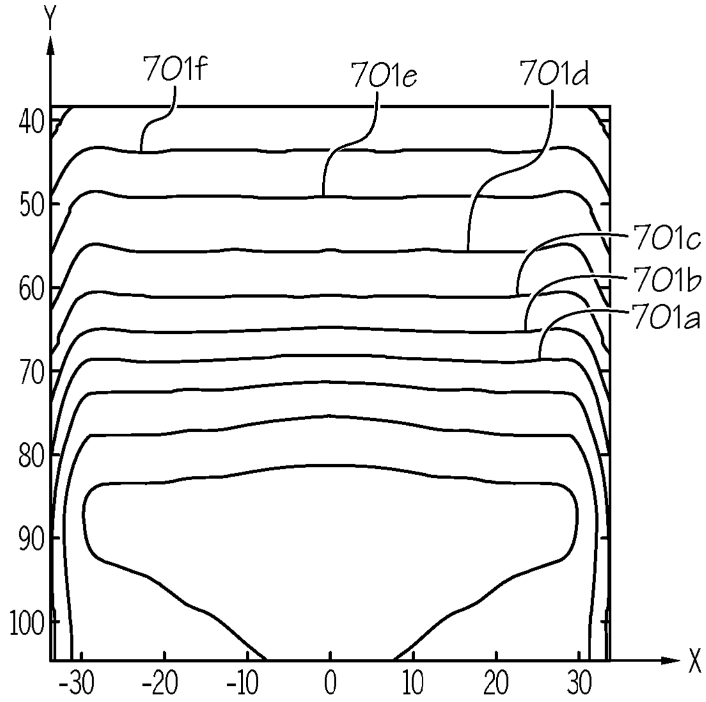
Y
701f
701e
701d
701c
701b
701a
40
50
60
70
80
90
100
-30
-20
-10
0
10
20
30
X

FIG. 7

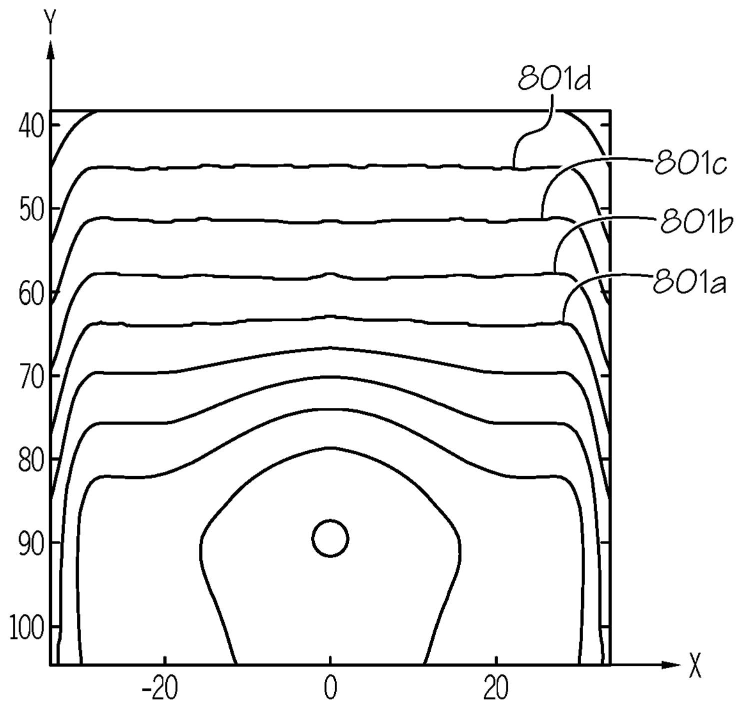
Y
801d
801c
801b
801a
40
50
60
70
80
90
100
-20
0
20
X

FIG. 8

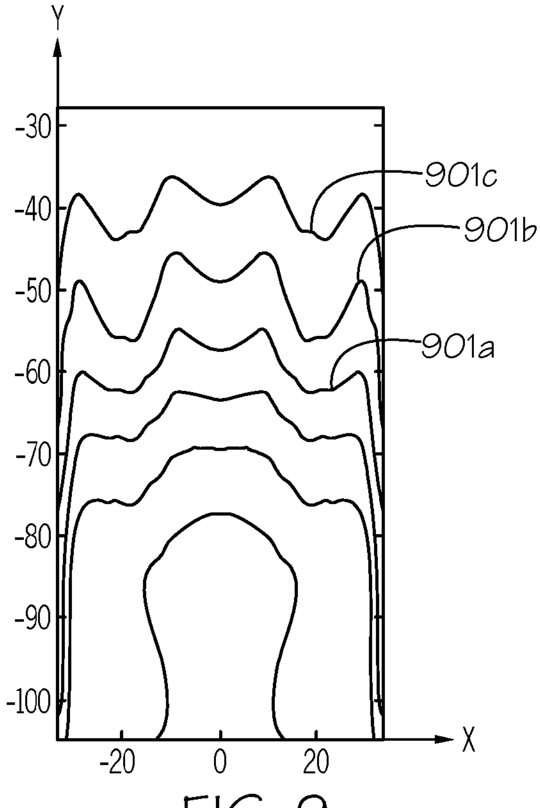
Y
-30
-40
-50
-60
-70
-80
-90
-100
-20
0
20
X
901c
901b
901a

FIG. 9

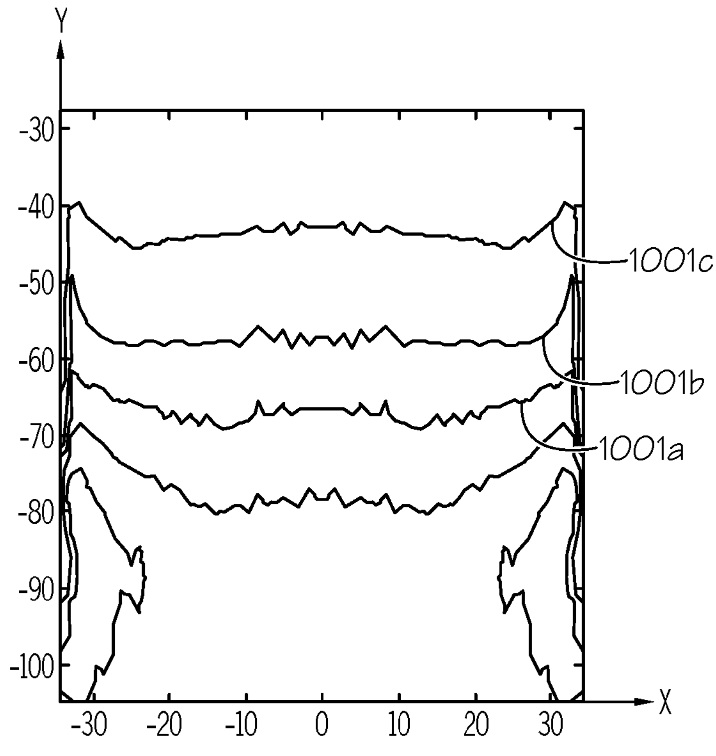
Y
-30
-40
-50
-60
-70
-80
-90
-100
-30
-20
-10
0
10
20
30
X
1001c
1001b
1001a

FIG. 10

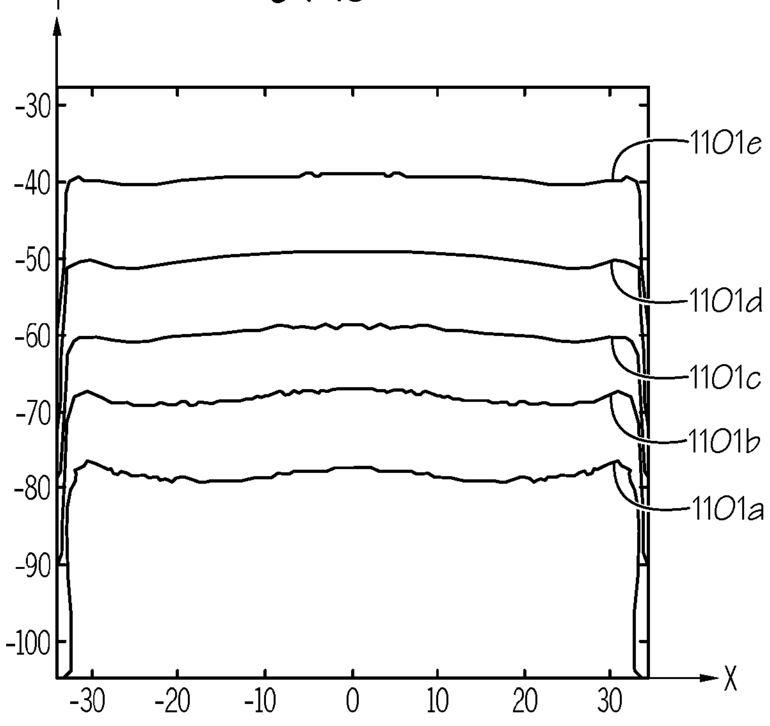
Y
-30
-40
-50
-60
-70
-80
-90
-100
-30
-20
-10
0
10
20
30
X
1101e
1101d
1101c
1101b
1101a

FIG. 11

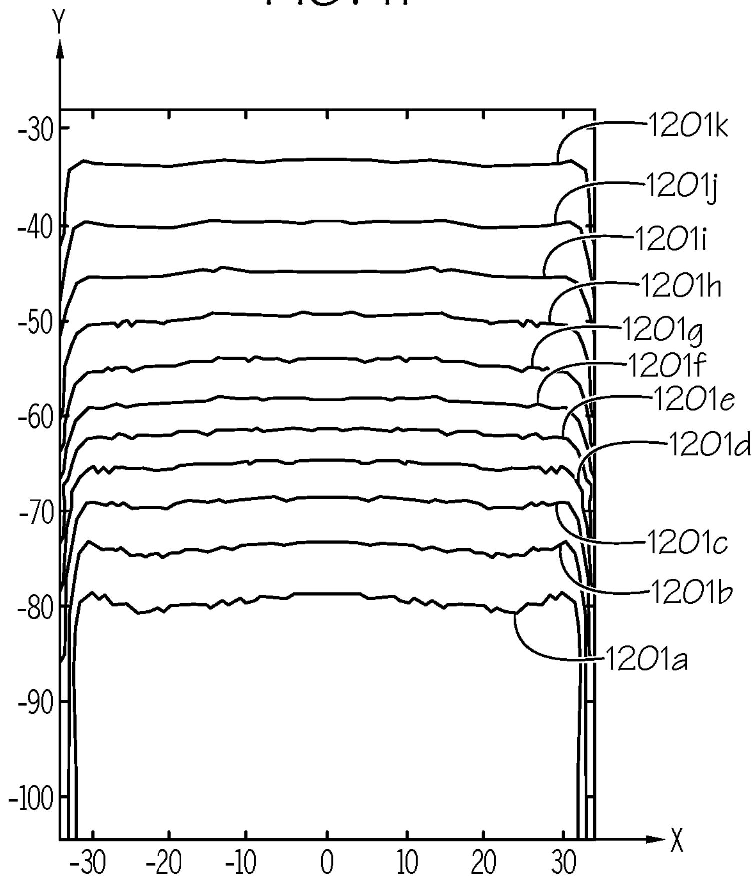
Y
-30
-40
-50
-60
-70
-80
-90
-100
-30
-20
-10
0
10
20
30
X
1201k
1201j
1201i
1201h
1201g
1201f
1201e
1201d
1201c
1201b
1201a

FIG. 12

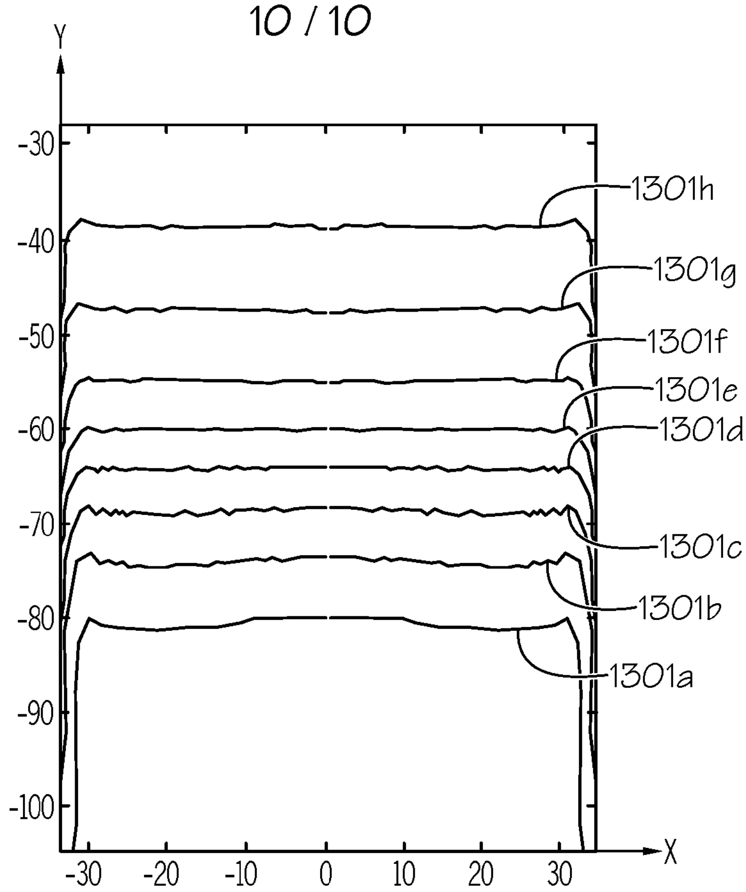
Y
-30
-40
-50
-60
-70
-80
-90
-100
X
-30
-20
-10
0
10
20
30
1301h
1301g
1301f
1301e
1301d
1301c
1301b
1301a

FIG. 13

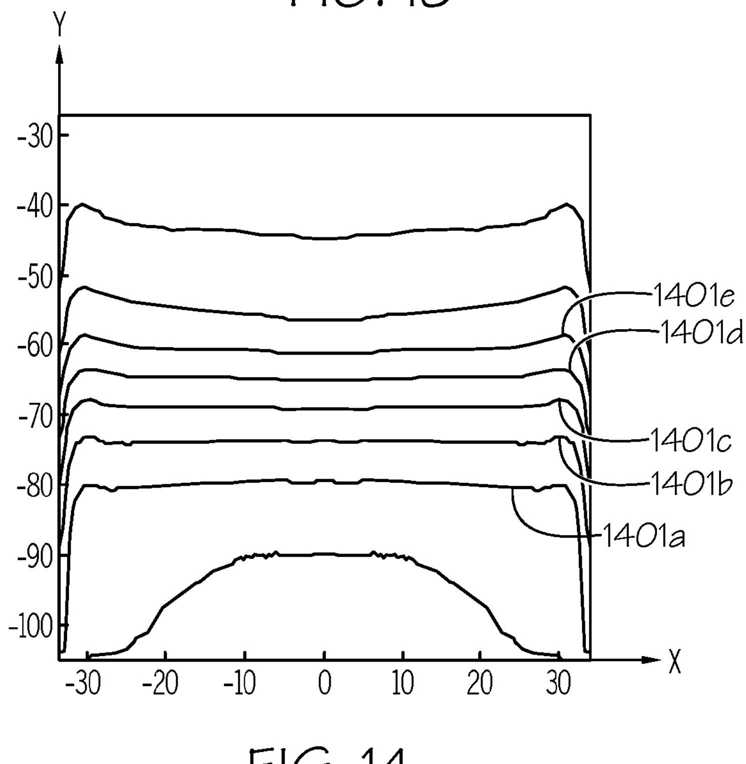
Y
-30
-40
-50
-60
-70
-80
-90
-100
X
-30
-20
-10
0
10
20
30
1401e
1401d
1401c
1401b
1401a

FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/026116

A. CLASSIFICATION OF SUBJECT MATTER

C03B 15/02(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C03B 15/02; C03B 40/02; C03B 35/24; C03B 17/06; C03B 18/02; C03B 27/052

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: glass, ribbon, cooling, vacuum port, convection

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2014-193780 A1 (CORNING INCORPORATED) 04 December 2014 See claims 1-16; paragraphs [0046]-[0049], [0054]-[0059]; figures 1-6.	1-32
A	US 2013-0133368 A1 (FOURNEL, OLIVIER) 30 May 2013 See the entire document.	1-32
A	US 2012-0318020 A1 (DELIA, ROBERT et al.) 20 December 2012 See the entire document.	1-32
A	US 2006-0042314 A1 (ABBOTT III, JOHN S. et al.) 02 March 2006 See the entire document.	1-32
A	WO 2011-066064 A2 (CORNING INCORPORATED) 03 June 2011 See the entire document.	1-32

☐ 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
18 July 2017 (18.07.2017)

Date of mailing of the international search report
18 July 2017 (18.07.2017)

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea
Facsimile No. +82-42-481-8578

Authorized officer
LEE, Ki Cheul
Telephone No. +82-42-481-3353

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/026116

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2014-193780 A1	04/12/2014	CN 105307988 A	03/02/2016
		JP 2016-523219 A	08/08/2016
		KR 10-2016-0014608 A	11/02/2016
		TW 201500302 A	01/01/2015
		US 2016-0107916 A1	21/04/2016
US 2013-0133368 A1	30/05/2013	CN 104169228 A	26/11/2014
		CN 104169228 B	19/10/2016
		EP 2785656 A1	08/10/2014
		JP 2015-500786 A	08/01/2015
		KR 10-2014-0105747 A	02/09/2014
		TW 201328992 A	16/07/2013
		TW I549915 B	21/09/2016
		US 9598301 B2	21/03/2017
		WO 2013-082067 A1	06/06/2013
US 2012-0318020 A1	20/12/2012	CN 103608307 A	26/02/2014
		CN 103608307 B	29/06/2016
		JP 2014-518190 A	28/07/2014
		JP 5990266 B2	07/09/2016
		KR 10-2014-0051897 A	02/05/2014
		TW 201309604 A	01/03/2013
		WO 2012-174353 A2	20/12/2012
		WO 2012-174353 A3	18/04/2013
US 2006-0042314 A1	02/03/2006	CN 101124174 A	13/02/2008
		CN 101124174 B	16/03/2011
		JP 2008-511535 A	17/04/2008
		JP 4954075 B2	13/06/2012
		KR 10-1208861 B1	05/12/2012
		KR 10-2007-0045356 A	02/05/2007
		TW I382003 B	11/01/2013
		WO 2006-026261 A2	09/03/2006
		WO 2006-026261 A3	09/08/2007
WO 2011-066064 A2	03/06/2011	CN 102725238 A	10/10/2012
		CN 102725238 B	01/07/2015
		JP 2013-512171 A	11/04/2013
		JP 5685264 B2	18/03/2015
		KR 10-2012-0102720 A	18/09/2012
		TW 201125828 A	01/08/2011
		TW I547448 B	01/09/2016
		WO 2011-066064 A3	03/11/2011