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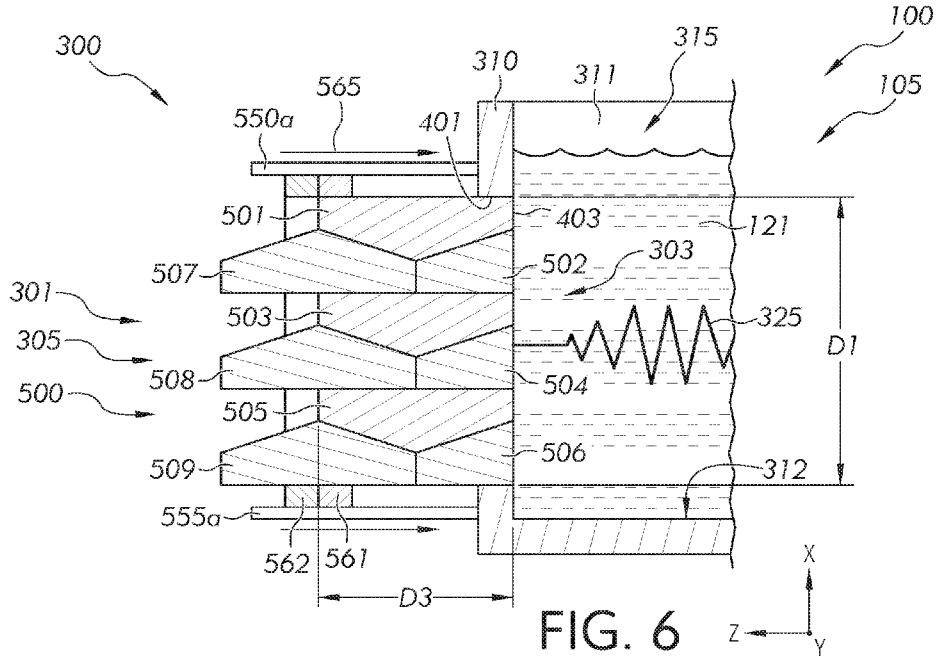


FIG. 6

(57) Abstract: An electrode assembly includes a plurality of blocks stacked along a first axis. The plurality of blocks span a first distance along the first axis and a second distance along a second axis. The first distance and the second distance define a first face of the electrode assembly, and the plurality of blocks span a third distance from the first face of the electrode assembly to a second face of the electrode assembly along a third axis. A first dimension of a first block of the plurality of blocks is greater than a second dimension of a second block of the plurality of blocks. An apparatus includes the electrode assembly and a vessel. Methods of processing material in the vessel are also provided.



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## APPARATUS AND METHOD FOR PROCESSING MATERIAL

**CROSS-REFERENCE TO RELATED APPLICATION**

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 62/646556 filed on March 22, 2018, 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 processing material and, more particularly, to an electrode assembly including a plurality of blocks, an apparatus including the electrode assembly and a vessel, and methods for processing material in the vessel including supplying electrical energy to the electrode assembly.

**BACKGROUND**

[0003] It is known to provide a glass manufacturing apparatus designed to produce a glass article from a quantity of molten material. Conventional glass manufacturing apparatus include a furnace including electrodes designed to process (e.g., melt, heat) batch material into a quantity of molten material.

**SUMMARY**

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

[0005] In some embodiments, an electrode assembly includes a plurality of blocks stacked along a first axis in a first direction. The plurality of blocks span a first distance along the first axis and a second distance along a second axis in a second direction perpendicular to the first direction. The first distance and the second distance define a first face of the electrode assembly, and the plurality of blocks span a third distance from the first face of the electrode assembly to a second face of the electrode assembly along a third axis in a third direction perpendicular to the first direction and the second direction. A first dimension of a first block of the plurality of blocks defined along the third axis from a first end of the first block to a second end of the first block is greater than a second dimension of a second block of the

plurality of blocks defined along the third axis from a first end of the second block to a second end of the second block.

[0006] In some embodiments, the first end of the first block defines a first portion of the first face, and the first end of the second block defines a second portion of the first face.

[0007] In some embodiments, the first face defines a planar surface of the electrode assembly.

[0008] In some embodiments, the first block includes a first surface extending from the first end of the first block to the second end of the first block, and the first surface defines a non-planar boundary of the first block.

[0009] In some embodiments, the second block includes a second surface extending from the first end of the second block to the second end of the second block, and a first portion of the first surface of the first block faces a portion of the second surface of the second block.

[0010] In some embodiments, the first portion of the first surface of the first block abuts the portion of the second surface of the second block at a first interface.

[0011] In some embodiments, a third dimension of a third block of the plurality of blocks defined along the third axis from a first end of the third block to a second end of the third block is greater than the second dimension, and the first end of the third block faces the second end of the second block.

[0012] In some embodiments, the first dimension equals the third dimension.

[0013] In some embodiments, the third block includes a third surface extending from the first end of the third block to the second end of the third block, the third surface defines a non-planar boundary of the third block, and a second portion of the first surface of the first block faces a portion of the third surface of the third block.

[0014] In some embodiments, the first end of the third block abuts the second end of the second block at a second interface, and the second portion of the first surface of the first block abuts the portion of the third surface of the third block at a third interface.

[0015] In some embodiments, the electrode assembly further includes a first frame circumscribing the plurality of blocks along the first axis and the second axis.

[0016] In some embodiments, the first frame is movable along the third axis.

[0017] In some embodiments, the first frame applies a first clamping force on the plurality of blocks along at least one of the first axis and the second axis.

[0018] In some embodiments, the first frame comprises a first fastener oriented to at least one of increase and decrease the first clamping force.

[0019] In some embodiments, the electrode assembly includes a second frame circumscribing the plurality of blocks along the first axis and the second axis. The second frame is movable along the third axis, the second frame applies a second clamping force on the plurality of blocks along at least one of the first axis and the second axis, and the second frame includes a second fastener oriented to at least one of increase and decrease the second clamping force. The first frame and the second frame are independently movable along the third axis.

[0020] In some embodiments, an apparatus includes the electrode assembly and a vessel including at least one wall defining a containment area of the vessel. The at least one wall includes an aperture defining an opening receiving at least a portion of the electrode assembly.

[0021] In some embodiments, the vessel includes a melting vessel for a glass manufacturing system.

[0022] In some embodiments, a position of the electrode assembly is adjustable relative to the opening of the wall.

[0023] In some embodiments, a method of processing material in the vessel includes supplying electrical energy to the electrode assembly and heating the material in the containment area of the vessel with the electrical energy.

[0024] In some embodiments, the method includes adjusting a position of the electrode assembly relative to the opening of the wall while heating the material.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0025] These and other features, embodiments and advantages are better understood when the following detailed description is read with reference to the accompanying drawings, in which:

[0026] **FIG. 1** schematically illustrates an exemplary embodiment of a glass manufacturing apparatus in accordance with embodiments of the disclosure;

[0027] **FIG. 2** shows a perspective cross-sectional view of the glass manufacturing apparatus along line **2-2** of **FIG. 1** including a glass forming apparatus in accordance with embodiments of the disclosure;

[0028] FIG. 3 shows a plan view of a portion of the glass manufacturing apparatus along line 3-3 of FIG. 1 including a vessel and a heating device in accordance with embodiments of the disclosure;

[0029] FIG. 4 shows a cross-sectional view of the vessel and the heating device along line 4-4 of FIG. 3 in accordance with embodiments of the disclosure;

[0030] FIG. 5 shows a side view of the vessel of the glass manufacturing apparatus along line 5-5 of FIG. 3 including an electrode assembly in accordance with embodiments of the disclosure;

[0031] FIG. 6 shows a partial cross-sectional view of the vessel and the heating device of FIG. 4 including an electrode assembly including a plurality of blocks in accordance with embodiments of the disclosure;

[0032] FIG. 7 shows an exemplary embodiment of the partial cross-sectional view of the electrode assembly including the plurality of blocks of FIG. 6 in accordance with embodiments of the disclosure;

[0033] FIG. 8 shows an exemplary embodiment of the partial cross-sectional view of the electrode assembly including the plurality of blocks of FIG. 7 in accordance with embodiments of the disclosure;

[0034] FIG. 9 shows an exemplary embodiment of the partial cross-sectional view of the electrode assembly including the plurality of blocks of FIG. 8 in accordance with embodiments of the disclosure;

[0035] FIG. 10 shows an exemplary embodiment of the partial cross-sectional view of the electrode assembly including the plurality of blocks of FIG. 9 in accordance with embodiments of the disclosure;

[0036] FIG. 11 shows an exemplary embodiment of the partial cross-sectional view of the electrode assembly including the plurality of blocks of FIG. 10 in accordance with embodiments of the disclosure;

[0037] FIG. 12 shows an exemplary embodiment of the partial cross-sectional view of the electrode assembly including the plurality of blocks of FIG. 11 in accordance with embodiments of the disclosure;

[0038] FIG. 13 shows a perspective view of an exemplary block of the plurality of blocks of the electrode assembly of FIGS. 6-12 in accordance with embodiments of the disclosure;

[0039] FIG. 14 shows an exemplary embodiment of a plurality of exemplary blocks of FIG. 13 stacked in accordance with embodiments of the disclosure;

[0040] FIG. 15 shows an exemplary embodiment of a frame and a fastener of the electrode assembly at view 15 of FIG. 5 in accordance with embodiments of the disclosure;

[0041] FIG. 16 shows an alternate exemplary embodiment of a frame and a fastener of the electrode assembly at view 15 of FIG. 5 in accordance with embodiments of the disclosure; and

[0042] FIG. 17 shows an alternate exemplary embodiment of a frame and a fastener of the electrode assembly at view 15 of FIG. 5 in accordance with embodiments of the disclosure.

#### **DETAILED DESCRIPTION**

[0043] Embodiments will now be described more fully hereinafter with reference to the accompanying drawings in which exemplary embodiments are shown. Whenever possible, the same reference numerals are used throughout the drawings to refer to the same or like parts. However, this disclosure may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein.

[0044] It is to be understood that specific embodiments disclosed herein are intended to be exemplary and therefore non-limiting. For purposes of the disclosure, in some embodiments, a glass manufacturing apparatus can optionally include a glass forming apparatus that forms a glass article (e.g., a glass ribbon and/or a glass sheet) from a quantity of molten material. For example, in some embodiments, the glass manufacturing apparatus can optionally include a glass forming apparatus such as a slot draw apparatus, float bath apparatus, down-draw apparatus, up-draw apparatus, press-rolling apparatus, or other glass forming apparatus that forms a glass article. In some embodiments, the glass article can include one or more optical characteristics desirable with respect to a variety of articles (e.g., ophthalmic articles, display articles). For example, in some embodiments, the glass manufacturing apparatus can be employed to provide display articles (e.g., display glass sheets) that can be employed in a variety of display applications including, but not limited to, liquid crystal displays (LCDs), electrophoretic displays (EPD), organic light emitting diode displays (OLEDs), plasma display panels (PDPs), and other electronic displays.

[0045] As schematically illustrated in FIG. 1, in some embodiments, an exemplary glass manufacturing apparatus 100 can include a glass forming apparatus 101 including a forming vessel 140 designed to produce a glass ribbon 103 from a quantity of molten material 121. In some embodiments, the glass ribbon 103 can include a central portion 152 disposed between opposite, relatively thick edge beads formed along a first outer edge 153 and a second outer edge 155 of the glass ribbon 103. Additionally, in some embodiments, a glass sheet 104 can be separated from the glass ribbon 103 along a separation path 151 by a glass separator 149 (e.g., scribe, score wheel, diamond tip, laser, etc.). In some embodiments, before or after separation of the glass sheet 104 from the glass ribbon 103, the relatively thick edge beads formed along the first outer edge 153 and the second outer edge 155 can be removed to provide the central portion 152 as a high-quality glass sheet 104 having a uniform thickness. In some embodiments, the resulting high-quality glass sheet 104 can then be at least one of processed and employed in a variety of applications.

[0046] In some embodiments, the glass manufacturing apparatus 100 can include a melting vessel 105 oriented to receive batch material 107 from a storage bin 109. The batch material 107 can be introduced by a batch delivery device 111 powered by a motor 113. In some embodiments, an optional controller 115 can be operated to activate the motor 113 to introduce a desired amount of batch material 107 into the melting vessel 105, as indicated by arrow 117. The melting vessel 105 can heat the batch material 107 to provide molten material 121. In some embodiments, a glass melt probe 119 can be employed to measure a level of molten material 121 within a standpipe 123 and communicate the measured information to the controller 115 by way of a communication line 125.

[0047] Additionally, in some embodiments, the glass manufacturing apparatus 100 can include a first conditioning station including a fining vessel 127 located downstream from the melting vessel 105 and coupled to the melting vessel 105 by way of a first connecting conduit 129. In some embodiments, molten material 121 can be gravity fed from the melting vessel 105 to the fining vessel 127 by way of the first connecting conduit 129. For example, in some embodiments, gravity can drive the molten material 121 to pass through an interior pathway of the first connecting conduit 129 from the melting vessel 105 to the fining vessel 127. Additionally, in

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

**[0048]** In some embodiments, the glass manufacturing apparatus **100** can further include a second conditioning station including a mixing chamber **131** that can be located downstream from the fining vessel **127**. The mixing chamber **131** can be employed to provide a homogenous composition of molten material **121**, thereby reducing or eliminating inhomogeneity that may otherwise exist within the molten material **121** exiting the fining vessel **127**. As shown, the fining vessel **127** can be coupled to the mixing chamber **131** by way of a second connecting conduit **135**. In some embodiments, molten material **121** can be gravity fed from the fining vessel **127** to the mixing chamber **131** by way of the second connecting conduit **135**. For example, in some embodiments, gravity can drive the molten material **121** to pass through an interior pathway of the second connecting conduit **135** from the fining vessel **127** to the mixing chamber **131**.

**[0049]** Additionally, in some embodiments, the glass manufacturing apparatus **100** can include a third conditioning station including a delivery vessel **133** that can be located downstream from the mixing chamber **131**. In some embodiments, the delivery vessel **133** can condition the molten material **121** to be fed into an inlet conduit **141**. For example, the delivery vessel **133** can function as an accumulator and/or flow controller to adjust and provide a consistent flow of molten material **121** to the inlet conduit **141**. As shown, the mixing chamber **131** can be coupled to the delivery vessel **133** by way of a third connecting conduit **137**. In some embodiments, molten material **121** can be gravity fed from the mixing chamber **131** to the delivery vessel **133** by way of the third connecting conduit **137**. For example, in some embodiments, gravity can drive the molten material **121** to pass through an interior pathway of the third connecting conduit **137** from the mixing chamber **131** to the delivery vessel **133**. As further illustrated, in some embodiments, a delivery pipe **139** (e.g., downcomer) can be positioned to deliver molten material **121** to the inlet conduit **141** of the forming vessel **140**.

**[0050]** Various embodiments of forming vessels can be provided in accordance with features of the disclosure including a forming vessel with a wedge for fusion drawing the glass ribbon, a forming vessel with a slot to slot draw the glass ribbon, or a forming vessel provided with press rolls to press roll the glass ribbon

from the forming vessel. By way of illustration, the forming vessel **140** shown and disclosed below can be provided to fusion draw molten material **121** off a root **145** of a forming wedge **209** to produce the glass ribbon **103**. For example, in some embodiments, the molten material **121** can be delivered from the inlet conduit **141** to the forming vessel **140**. The molten material **121** can then be formed into the glass ribbon **103** based at least in part on the structure of the forming vessel **140**. For example, as shown, the molten material **121** can be drawn off the bottom edge (e.g., root **145**) of the forming vessel **140** along a draw path extending in a draw direction **157** of the glass manufacturing apparatus **100**. In some embodiments, edge directors **163a**, **163b** can direct the molten material **121** off the forming vessel **140** and define, at least in part, a width “**W**” of the glass ribbon **103**. In some embodiments, the width “**W**” of the glass ribbon **103** can extend between the first outer edge **153** of the glass ribbon **103** and the second outer edge **155** of the glass ribbon **103**.

[0051] FIG. 2 shows a cross-sectional perspective view of the glass manufacturing apparatus **100** along line 2-2 of FIG. 1. In some embodiments, the forming vessel **140** can include a trough **201** oriented to receive the molten material **121** from the inlet conduit **141**. For illustrative purposes, cross-hatching of the molten material **121** is removed from FIG. 2 for clarity. The forming vessel **140** can further include the forming wedge **209** including a pair of downwardly inclined converging surface portions **207a**, **207b** extending between opposed ends **210a**, **210b** (See FIG. 1) of the forming wedge **209**. The pair of downwardly inclined converging surface portions **207a**, **207b** of the forming wedge **209** can converge along the draw direction **157** to intersect along a bottom edge of the forming wedge **209** to define the root **145** of the forming vessel **140**. A draw plane **213** of the glass manufacturing apparatus **100** can extend through the root **145** along the draw direction **157**. In some embodiments, the glass ribbon **103** can be drawn in the draw direction **157** along the draw plane **213**. As shown, the draw plane **213** can bisect the forming wedge **209** through the root **145** although, in some embodiments, the draw plane **213** can extend at other orientations relative to the root **145**.

[0052] Additionally, in some embodiments, the molten material **121** can flow in a direction **159** into the trough **201** of the forming vessel **140**. The molten material **121** can then overflow from the trough **201** by simultaneously flowing over

corresponding weirs **203a**, **203b** and downward over the outer surfaces **205a**, **205b** of the corresponding weirs **203a**, **203b**. Respective streams of molten material **121** can then flow along the downwardly inclined converging surface portions **207a**, **207b** of the forming wedge **209** to be drawn off the root **145** of the forming vessel **140**, where the flows converge and fuse into the glass ribbon **103**. The glass ribbon **103** can then be fusion drawn off the root **145** in the draw plane **213** along the draw direction **157**. In some embodiments, the glass separator **149** (see **FIG. 1**) can then subsequently separate the glass sheet **104** from the glass ribbon **103** along the separation path **151**. As illustrated, in some embodiments, the separation path **151** can extend along the width “**W**” of the glass ribbon **103** between the first outer edge **153** and the second outer edge **155**. Additionally, in some embodiments, the separation path **151** can extend perpendicular to the draw direction **157** of the glass ribbon **103**. Moreover, in some embodiments, the draw direction **157** can define a direction along which the glass ribbon **103** can be fusion drawn from the forming vessel **140**.

[0053] As shown in **FIG. 2**, the glass ribbon **103** can be drawn from the root **145** with a first major surface **215a** of the glass ribbon **103** and a second major surface **215b** of the glass ribbon **103** facing opposite directions and defining a thickness “**T**” (e.g., average thickness) of the glass ribbon **103**. In some embodiments, the thickness “**T**” of the glass ribbon **103** can be less than or equal to about 2 millimeters (mm), less than or equal to about 1 millimeter, less than or equal to about 0.5 millimeters, for example, less than or equal to about 300 micrometers ( $\mu\text{m}$ ), less than or equal to about 200 micrometers, or less than or equal to about 100 micrometers, although other thicknesses may be provided in further embodiments. For example, in some embodiments, the thickness “**T**” of the glass ribbon **103** can be from about 50  $\mu\text{m}$  to about 750  $\mu\text{m}$ , from about 100  $\mu\text{m}$  to about 700  $\mu\text{m}$ , from about 200  $\mu\text{m}$  to about 600  $\mu\text{m}$ , from about 300  $\mu\text{m}$  to about 500  $\mu\text{m}$ , from about 50  $\mu\text{m}$  to about 500  $\mu\text{m}$ , from about 50  $\mu\text{m}$  to about 700  $\mu\text{m}$ , from about 50  $\mu\text{m}$  to about 600  $\mu\text{m}$ , from about 50  $\mu\text{m}$  to about 500  $\mu\text{m}$ , from about 50  $\mu\text{m}$  to about 400  $\mu\text{m}$ , from about 50  $\mu\text{m}$  to about 300  $\mu\text{m}$ , from about 50  $\mu\text{m}$  to about 200  $\mu\text{m}$ , from about 50  $\mu\text{m}$  to about 100  $\mu\text{m}$ , including all ranges and subranges of thicknesses therebetween. In addition, the glass ribbon **103** can include a variety of compositions including, but not limited to, soda-lime glass, borosilicate glass, alumino-borosilicate glass, alkali-containing glass, or alkali-free glass.

[0054] FIG. 3 shows a plan view of a portion of the glass manufacturing apparatus 100 including the melting vessel 105 along line 3-3 of FIG. 1, with a top portion (e.g., lid, roof, ceiling) of the melting vessel 105 removed for clarity. Thus, unless otherwise noted, it is to be understood that, in some embodiments, the melting vessel 105 can include a fixed or removable top portion without departing from the scope of the disclosure. Additionally, unless otherwise noted, in some embodiments, the top portion of the melting vessel 105 can be open to, for example, the environment outside of the melting vessel 105, and a free surface of the molten material 121 can face the open top portion. In some embodiments, the melting vessel 105 can include a wall 310 including an inner surface 311, 312 defining, at least in part, a containment area 315 (e.g., a volume) of the melting vessel 105. For example, in some embodiments, a sidewall inner surface 311 and a bottom wall inner surface 312 can define, at least in part, the containment area 315 of the melting vessel 105. As shown, in some embodiments, the containment area 315 can contain material (e.g., batch material 107, molten material 121); however, unless otherwise noted, it is to be understood that the melting vessel 105 can be empty (e.g., provided without material) in some embodiments, without departing from the scope of the disclosure.

[0055] In some embodiments, the wall 310 of the melting vessel 105 can include (e.g., be manufactured from) metallic and/or non-metallic materials including but not limited to one or more of a thermal insulating refractory material (e.g., ceramic, silicon carbide, zirconia, zircon, chromium oxide). Additionally, in some embodiments the inner surface 311, 312 of the melting vessel 105 can include a layer (not shown) of corrosion resistant material (e.g., platinum, platinum alloys) to provide a corrosion resistant barrier between the material 107, 121 contained within the containment area 315 and the wall 310. In some embodiments, the wall 310 of the melting vessel 105 can include material selected to resist structural degradation and deformation (e.g., warp, sag, creep, fatigue, corrosion, breakage, cracking, thermal shock, mechanical shock, etc.) caused by exposure to one or more of an elevated temperature (e.g., temperatures at or below 2100°C), a corrosive chemical (e.g., boron, phosphorus, sodium oxide), and an external force. In some embodiments, the wall 310 can be manufactured as a solid, monolithic structure; however, in some embodiments, a plurality of separate structures (e.g., bricks) can be combined (e.g.,

stacked) to provide at least a portion of the wall **310**. For purposes of the disclosure, regardless of the manner in which the wall **310** is constructed, a container (e.g., containment vessel) can include an inner surface **311**, **312** defining at least a portion of a containment area **315** oriented to contain material **107**, **121** within the containment area **315** without departing from the scope of the disclosure.

[0056] As indicated by arrow **117**, in some embodiments, the batch material **107** can be introduced by the batch delivery device **111** into the containment area **315** of the melting vessel **105**. In some embodiments, the melting vessel **105** can heat the batch material **107** to provide molten material **121** within the containment area **315**. Additionally, in some embodiments, the melting vessel **105** can be operable to raise or lower the temperature of the molten material **121** contained within the containment area **315**. For example, in some embodiments, the glass manufacturing apparatus **100** can include a heating device **300** (e.g., heater) that can include a first electrode **301** and a second electrode **302** operable to heat (e.g., melt) the batch material **107** to provide the molten material **121**. In some embodiments, the first electrode **301** and the second electrode **302** can be identical to one another. Likewise, in some embodiments, structures and components associated and/or operable with the first electrode **301** can be identical to structures and components associated and/or operable with the second electrode **302**. As such, unless otherwise noted, for purposes of the disclosure, features of the first electrode **301** as well as structures and components associated and/or operable with the first electrode **301** can equally apply to features of the second electrode **302** as well as structures and components associated and/or operable with the second electrode **302**. Furthermore, although not shown, in some embodiments, features of the second electrode **302** as well as structures and components associated and/or operable with the second electrode **302** may not be identical to corresponding features of the first electrode **301** as well as corresponding structures and components associated and/or operable with the first electrode **301**.

[0057] In some embodiments, one or more additional heating devices (not shown) can be provided to, for example, initially melt the batch material **107** to provide the molten material **121**. In some embodiments, the heating device **300** including the first electrode **301** and the second electrode **302** can then be employed to further melt the batch material **107** and/or to further heat the molten material **121**.

Moreover, in some embodiments one or more additional heating devices (not shown) including but not limited to gas heaters, electric heaters, and resistance heaters can be provided, in combination with the heating device **300**, to provide additional heat to the material **107**, **121** contained within the containment area **315** of the melting vessel **105** without departing from the scope of the disclosure.

**[0058]** In some embodiments, the heating device **300** can include an electrical circuit including a first electrical lead **307** electrically connected to the first electrode **301** and a second electrical lead **308** electrically connected to the second electrode **302**. In some embodiments, the material (e.g., batch material **107**, molten material **121**) can include material properties that cause the material to behave as an electrical resistor which converts an electric current **325** passing through the material **107**, **121** into heat energy based at least on the principle of Joule heating. Accordingly, in some embodiments, the Joule heating can be based at least in part on the Joule law ( $P = I^2 \times R$ ), where “P” is the electrical heating power, “I” is the electric current **325**, and “R” is the electrical resistivity of the material through which the electric current **325** passes. For example, in some embodiments, electric current **325** (provided by first electrical lead **307**) can pass from a front face **303** of the first electrode **301**, through the material **107**, **121** contained in the containment area **315**, to a front face **304** of the second electrode **302**. Likewise, in some embodiments, electric current **325** (provided by second electrical lead **308**) can pass from the front face **304** of the second electrode **302**, through the material **107**, **121** contained in the containment area **315**, to the front face **303** of the first electrode **301**. Accordingly, in some embodiments, based at least in part on the conversion of the electric current **325** into heat energy, one or more features of the heating device **300** can operate to increase a temperature of the material **107**, **121** and/or maintain a temperature of the material **107**, **121** contained within the containment area **315** while operating the glass manufacturing apparatus **100**.

**[0059]** In some embodiments, the heating device **300** can be employed to, for example, at least one of control and reduce temperature fluctuations and temperature gradients of the material **107**, **121** contained within the containment area **315** of the melting vessel **105**. For example, in some embodiments, one or more features of the heating device **300** can uniformly heat the batch material **107** to provide the molten

material **121** contained within the vessel **105** with a uniform, controlled temperature. The uniform, controlled temperature of the molten material **121** can, in some embodiments, provide a better quality glass ribbon **103** relative to glass ribbons formed with molten material **121** that includes temperature gradients and/or temperature fluctuations. For example, as indicated by arrow **317**, in some embodiments, the molten material **121** can flow through the containment area **315** (e.g., across the electric current **325**) while being heated by the heating device **300**. In some embodiments, the molten material **121** can then be provided from the vessel **105** to the glass forming apparatus **101** (e.g., via the first connecting conduit **129**) for further processing to, for example, form the glass ribbon **103** (See **FIG. 1**).

**[0060]** In some embodiments, at least one of the first electrode **301** and the second electrode **302** can include (e.g., be manufactured from) metallic and/or non-metallic materials including but not limited to one or more of tin oxide, carbon, zirconia, molybdenum, platinum, and platinum alloys. In some embodiments, the front face **303** of the first electrode **301** and the front face **304** of the second electrode **302** can contact the material **107**, **121** contained within the containment area **315** of the melting vessel **105**. Accordingly, in some embodiments, at least one of the first electrode **301** and the second electrode **302** can include material selected to resist structural degradation and deformation (e.g., warp, sag, creep, fatigue, corrosion, breakage, cracking, thermal shock, mechanical shock, etc.) caused by exposure to one or more of an elevated temperature (e.g., temperatures at or below 2100°C), a corrosive chemical (e.g., boron, phosphorus, sodium oxide), and an external force. Moreover, in some embodiments, at least one of the first electrode **301** and the second electrode **302** can be manufactured as a solid (e.g., single, monolithic) structure; however, in some embodiments, as discussed more fully below, a plurality of separate structures (e.g., bricks, blocks) can be combined (e.g., stacked) to provide at least a portion of at least one of the first electrode **301** and the second electrode **302**. In some embodiments, constructing the electrodes **301**, **302** from a plurality of separate structures (e.g., bricks, blocks) can help simplify and reduce costs of fabrication of the electrodes **301**, **302**.

**[0061]** In some embodiments, based at least on the heat energy provided by electric current **325** to the material **107**, **121** contained within the containment area **315** of the melting vessel **105**, a temperature of a rear face **305** of the first electrode

**301** can be less than a temperature of the front face **303** of the first electrode **301**. Likewise, in some embodiments, based at least on the heat energy provided by electric current **325** to the material **107, 121** contained within the containment area **315** of the melting vessel **105**, a temperature of a rear face **306** of the second electrode **302** can be less than a temperature of the front face **304** of the second electrode **302**. Additionally, in some embodiments, the rear face **305** of the first electrode **301** and/or the rear face **306** of the second electrode **302** can be cooled with one or more of liquid (e.g., water), gas (e.g., air), solid (e.g., heat sink) to, for example, regulate a temperature of one or more electrical components (e.g., electrical leads **307, 308** and associated electrical components) electrically connected to the first electrode **301** and the second electrode **302** based on one or more of conduction heat transfer, convection heat transfer, and radiation heat transfer.

[0062] As further illustrated in **FIG. 4**, which shows a cross-sectional view of the melting vessel **105** along line **4-4** of **FIG. 3**, in some embodiments the first electrode **301** can be positioned in a first aperture **401** defining a first opening **403** in the wall **310** of the melting vessel **105**, and the second electrode **302** can be positioned in a second aperture **402** defining a second opening **404** in the wall **310** of the melting vessel **105**. In some embodiments, the first aperture **401** can be positioned opposite the second aperture **402** with the first opening **403** facing the second opening **404**. For example, in some embodiments, the first opening **403** and the second opening **404** can be aligned along a common axis. Additionally, in some embodiments, the front face **303** of the first electrode **301** can face the front face **304** of the second electrode **302** (e.g., be aligned along a common axis) with one or more surfaces of the front faces **303, 304** contacting the material **107, 121** contained within the containment area **315** of the melting vessel **105**. Accordingly, in some embodiments, electric current **325** can pass from the front face **303** of the first electrode **301** positioned in the first opening **403** of the first aperture **401** through the material **107, 121** contained in the containment area **315**, to the front face **304** of the second electrode **302** positioned in the second opening **404** of the second aperture **402**. Likewise, in some embodiments, electric current **325** can pass from the front face **304** of the second electrode **302** positioned in the second opening **404** of the second aperture **402**, through the material

107, 121 contained in the containment area 315, to the front face 303 of the first electrode 301 positioned in the first opening 403 of the first aperture 401.

[0063] In some embodiments, at least one of the front face 303 of the first electrode 301 and the front face 304 of the second electrode 302 can wear (e.g., degrade, reduce), for example, over a duration of time based at least on operation of the heating device 300 and contact with the material 107, 121. Accordingly, as discussed more fully below, in some embodiments, the first electrode 301 can be selectively translated relative to the first opening 403 along an adjustment path extending in direction 351 to translate the front face 303 along the adjustment path in the direction 351. In some embodiments, translating the first electrode 301 relative to the first opening 403 in direction 351 can compensate for the structural degradation of the front face 303 caused by wear while operating the glass manufacturing apparatus 100. Likewise, in some embodiments, the second electrode 302 can be selectively translated relative to the second opening 404 along an adjustment path extending in direction 352 to translate the front face 304 along the adjustment path in the direction 352. In some embodiments, translating the second electrode 302 relative to the second opening 404 in direction 352 can compensate for the structural degradation of the front face 304 caused by wear while operating the glass manufacturing apparatus 100.

[0064] In some embodiments, the inner surface 311, 312 of the wall 310 as well as the front face 303 of the first electrode 301 and the front face 304 of the second electrode 302 can define, at least in part, the containment area 315 of the melting vessel 105. Additionally, in some embodiments, the front faces 303, 304 of the electrodes 301, 302 can be flush with the inner surface 311 of the wall 310. For example, in some embodiments, the front faces 303, 304 of the electrodes 301, 302 can be positioned to be flush and/or translated in respective directions 351, 352 to be flush with the inner surface 311 of the wall 310 while operating the glass manufacturing apparatus 100. In addition or alternatively, in some embodiments, the front faces 303, 304 of the electrodes 301, 302 can be positioned to be recessed or protruding and/or translated in respective directions 351, 352 to be recessed or protruding with respect to the inner surface 311 of the wall 310 while operating the glass manufacturing apparatus 100. Accordingly, in some embodiments, based at least in part on the conversion of the electric current 325 into heat energy, one or

more features of the heating device **300** can operate to increase a temperature of the material **107**, **121** and/or maintain a temperature of the material **107**, **121** contained within the containment area **315**.

[0065] Moreover, although described with respect to features of the melting vessel **105**, unless otherwise noted, it is to be understood that, in some embodiments, one or more features of the heating device **300** can be provided, alone or in combination, with one or more containers (e.g., containment vessels), including containers not explicitly disclosed, to, for example, heat material, including material not explicitly disclosed, contained within a containment area of the one or more containers, without departing from the scope of the disclosure. In some embodiments, exemplary vessels employing the heating device **300** can process molten material in a variety of methods including but not limited to fining, conditioning, containing, stirring, allowing to chemically react, bubbling a gas therein, cooling, heating, forming, holding, and flowing.

[0066] For example in some embodiments one or more features of the heating device **300** can be provided, alone or in combination, with one or more features of the glass manufacturing apparatus **100** (**FIG. 1**) and the glass forming apparatus **101** including, but not limited to, the melting vessel **105**, the storage bin **109**, the standpipe **123**, the fining vessel **127**, the first connecting conduit **129**, the mixing chamber **131**, the delivery vessel **133**, the second connecting conduit **135**, the third connecting conduit **137**, the delivery pipe **139**, and the forming vessel **140** to, for example, heat material (e.g., batch material **107**, molten material **121**) contained within such features. Moreover, although the melting vessel **105** is illustrated as a substantially cubic structure in **FIG. 3** and **FIG. 4**, unless otherwise noted, it is to be understood that, in some embodiments, the melting vessel **105** as well as other vessels incorporating the heating device **300** can include structure defining a wall of one or more profiles and shapes including but not limited to, a sphere, a rectangular box, a cylinder, a cone, or other three-dimensional shape oriented to include a containment area (e.g., volume) to contain material.

[0067] Exemplary embodiments of an exemplary heating device **300** will now be described with respect to **FIGS. 5-17**. In some embodiments, the heating device **300** can be employed to heat molten material **121** contained within the containment

area **315** of the melting vessel **105** with the understanding that, unless otherwise noted, one or more features of the heating device **300** can be employed, alone or in combination, in some embodiments, to heat material contained within a containment area of one or more other containers (e.g., containment vessels) in accordance with embodiments of the disclosure, without departing from the scope of the disclosure. Additionally, the heating device **300** can include a wide range of configurations. Therefore, in some embodiments, the first electrode **301** and features associated with the first electrode **301** can be identical to the second electrode **302** and features associated with the second electrode **302**. As such, embodiments of the electrodes **301**, **302** and structures associated with the electrodes **301**, **302** will be discussed with reference to the first electrode **301** with the understanding that, in some embodiments, such features and discussion can equally apply to the second electrode **302**.

[0068] FIG. 5 shows a side view of the melting vessel **105** including the rear face **305** of the first electrode **301** of the heating device **300** along line 5-5 of FIG. 3 in accordance with embodiments of the disclosure. Additionally, FIGS. 6-12 show various exemplary embodiments of a partial cross-sectional view of the melting vessel **105** and the heating device **300** of FIG. 4 including methods of processing material **121** with the heating device **300**. In some embodiments, the first electrode **301** can be defined as an electrode assembly **301** including a plurality of blocks **500**. With respect to FIGS. 5-12, fifteen blocks **501-515** are disclosed with the understanding that, in some embodiments, more or less blocks defining the plurality of blocks **500** can be provided without departing from the scope of the disclosure. Likewise, in some embodiments, with respect to shape, size, and orientation, each block can be identical, one or more blocks can be a portion (e.g., half-block) of one or more identical blocks, and one or more blocks can be different from one or more other blocks. In some embodiments, providing identical blocks and/or one or more blocks as a portion (e.g., half-block) of one or more identical blocks can provide advantages with respect to at least one of manufacture and cost of the plurality of blocks **500** that may otherwise not be obtained, for example, by providing a plurality of different blocks or one, single block of relatively larger size.

[0069] Moreover, for purposes of the disclosure, a standard three-dimensional (right-hand) cartesian coordinate system is provided in FIGS. 3-17 with a first axis “X” extending in a first direction, a second axis “Y” extending in a second direction

perpendicular to the first direction, and a third axis “Z” extending in a third direction perpendicular to the first direction and the second direction. Unless otherwise noted, the coordinate system provides a basis from which at least one of a relative spatial coordinate and a relative orientation of one or more features of the disclosure can be determined in accordance with embodiments of the disclosure. Additionally, in some embodiments, a different coordinate system can be provided to define at least one of a relative spatial coordinate and a relative orientation of one or more features of the disclosure without departing from the scope of the disclosure. For example, in some embodiments, the plurality of blocks **500** can be stacked along the first axis “X” extending in the first direction. In some embodiments, the stacked blocks **500** can span a first distance “D1” along the first axis “X”, a second distance “D2” along the second axis “Y” extending in the second direction perpendicular to the first direction, and a third distance “D3” along the third axis “Z” extending in the third direction perpendicular to the first direction and the second direction. In some embodiments, one or more of the distances “D1”, “D2”, and “D3” can correspond to an entire distance along the respective axes “X”, “Y”, “Z” which one or more blocks **501-515** of the plurality of blocks **500** spans. Likewise, in some embodiments, one or more of the distances “D1”, “D2”, and “D3” can correspond to less than the entire distance (e.g., a partial distance) along the respective axes “X”, “Y”, “Z” which one or more blocks **501-515** of the plurality of blocks **500** spans.

[0070] As shown in FIGS. 5-7, in some embodiments, with respect to the first axis “X”, block **501** can be stacked on half-block **502** and block **507**; block **503** can be stacked on half-block **504** and block **508**; and block **505** can be stacked on half-block **506** and block **509**. Similarly, half-block **502** and block **507** can be stacked on block **503**; and half-block **504** and block **508** can be stacked on block **505**, thereby providing the electrode assembly **301** including a plurality of stacked blocks **500**. In some embodiments, the first distance “D1” and the second distance “D2” can define the front face **303** of the electrode assembly **301**. For example, in some embodiments, providing one or more half-blocks **502**, **504**, **506** (or other partial-blocks) stacked with one or more whole blocks **501**, **503**, **505** (or corresponding partial-blocks), can provide the electrode assembly **301** with a front face **303** contacting the molten material **121** contained in the containment area **315** of the vessel **105**. In some

embodiments, the front face **303** can define a planar surface of the electrode assembly **301**. In some embodiments, other surface profiles including, but not limited to, non-planar surface profiles, angled surface profiles, staggered surface profiles, and stepped surface profiles can be provided in other embodiments based at least in part on the stacked configuration of the plurality of blocks **500** as well as relative positions and/or wear of the ends of the plurality of blocks **500** defining portions of the front face **303** of the electrode assembly **301** while operating the glass manufacturing apparatus **500**.

[0071] Additionally, in some embodiments, a first block of the stacked blocks **500** can be offset (e.g., staggered) relative to a second block of the stacked blocks **500** along the third axis “**Z**”. For example, as shown in **FIGS. 5-7**, in some embodiments, block **501** can be offset relative to half-block **502** along the third axis “**Z**” and block **507** can be offset relative to block **501** along the third axis “**Z**”; block **503** can be offset relative to half-block **504** along the third axis “**Z**” and block **508** can be offset relative to block **503** along the third axis “**Z**”; and block **505** can be offset relative to half-block **506** along the third axis “**Z**” and block **509** can be offset relative to block **505** along the third axis “**Z**”. Similarly, in some embodiments, block **503** can be offset relative to half-block **502** along the third axis “**Z**” and block **507** can be offset relative to block **503** along the third axis “**Z**”; and block **505** can be offset relative to half-block **504** along the third axis “**Z**” and block **508** can be offset relative to block **505** along the third axis “**Z**”. In some embodiments, the opposing rear face **305** of the electrode assembly **301** can include a non-planar profile based at least on the relative offset of the stacked blocks **500**.

[0072] In some embodiments, the heating device **300** and the electrode assembly **301** can further include one or more frames **561**, **562** circumscribing the stacked blocks **500** along the first axis “**X**” and the second axis “**Y**”. In some embodiments, each frame **561**, **562** can impart a clamping force on the stacked blocks **500** along at least one of the first axis “**X**” and the second axis “**Y**”. For example, in some embodiments, by imparting a clamping force along at least one of the first axis “**X**” and the second axis “**Y**”, in some embodiments, the frames **561**, **562** can hold the plurality of blocks **500** together in a stacked configuration to provide a structurally stable stack of blocks **500**. Likewise, in some embodiments, by imparting a clamping force along at least one of the first axis “**X**” and the second axis “**Y**”, in some embodiments, the frames **561**, **562** can force one or more faces (e.g., surfaces) of

adjacent blocks into abutting relationship to provide electrical conductivity among the plurality of blocks **500**. For example, in some embodiments, the electrical lead **307** (**FIG. 3-5**) can be electrically connected to the electrode assembly **301** and/or electrically connected to one or more of the frames **561**, **562** which can, likewise, be electrically connected to one or more blocks of the plurality of blocks **500** of the electrode assembly **301**. In some embodiments, the clamping force provided by the frames **561**, **562** can force (e.g., push, press, maintain) adjacent, abutting faces of the plurality of blocks **500** together to provide an electrically conductive interface between the plurality of blocks **500**. Accordingly, in some embodiments, electric current **325** (provided by the electrical lead **307**) can pass from the front face **303** of the electrode assembly **301**, through the material **121** contained in the containment area **315**, thereby heating the material **121** based on Joule heating.

[0073] In some embodiments, the frames **561**, **562** can be selectively movable along a path (e.g., path **565** in **FIG. 6** and **FIG. 7**) extending along the third axis “**Z**”. For example, in some embodiments, the frames **561**, **562** can be at least one of manually and automatically selectively moveable along one or more rails **550a**, **555a**, **550b**, **555b** of the heating device **300**. In some embodiments, the frames **561**, **562** can move along the rails **550a**, **555a**, **550b**, **555b** based on one or more of a rolling (e.g., wheeled) engagement, a geared engagement, a grooved engagement, a sliding engagement or other mechanical engagement or connection oriented to provide selective relative motion between the frames **561**, **562** and the rails **550a**, **555a**, **550b**, **555b**. Moreover, in some embodiments, frame **561** can be independently movable relative to frame **562** such that each frame **561**, **562** can be independently and selectively movable along a path (e.g., path **565** in **FIG. 6** and **FIG. 7**) extending along the third axis “**Z**”. As discussed more fully below, in some embodiments, each frame **561**, **562** can be independently and selectively movable along path **565** extending along the third axis “**Z**” relative to the rails **550a**, **555a**, **550b**, **555b** and/or relative to the plurality of blocks **500**.

[0074] Therefore, as schematically shown in **FIG. 6**, in some embodiments, one or more frames **561**, **562**, providing the clamping force to the plurality of blocks **500** along at least one of the first axis “**X**” and the second axis “**Y**”, can be selectively translated relative to the first opening **403** along the adjustment path **565** extending in

direction “Z” to translate the front face 303 of the electrode assembly 301 along the adjustment path 565 in direction “Z”. As schematically illustrated in FIG. 7, in some embodiments, translating one or more frames 561, 562 that are clamping the plurality of blocks 500 of the electrode assembly 301 relative to the first opening 403 along path 565 can move the front face 303 of the electrode assembly 301 along the adjustment path 565 to compensate for structural degradation of the front face 303 of the electrode assembly 301 caused by wear while operating the glass manufacturing apparatus 100. Moreover, as shown in FIG. 8, in some embodiments, additional blocks 510, 511, 512 can be added (e.g., stacked) with the stacked blocks 500. For example, in some embodiments, while operating the glass manufacturing apparatus 100, as the front face 303 of the electrode assembly 301 wears (e.g., degrades), one or more additional blocks 510, 511, 512 can be added to replace and replenish structure of the electrode assembly 301, as illustrated in FIG. 9.

[0075] Similarly, as schematically shown in FIG. 10, in some embodiments, after adding the one or more additional blocks 510, 511, 512 to the stacked blocks 500 of the electrode assembly 301, one or more frames 561, 562, providing the clamping force to the plurality of blocks 500 along at least one of the first axis “X” and the second axis “Y”, can be further selectively translated relative to the first opening 403 along the adjustment path 565 extending in direction “Z” to translate the front face 303 of the electrode assembly 301 along the adjustment path 565 in direction “Z” to compensate for further structural degradation of the front face 303 of the electrode assembly 301 caused by wear while operating the glass manufacturing apparatus 100. Likewise, as shown in FIG. 11, in some embodiments, additional blocks 513, 514, 515 can be added (e.g., stacked) with the stacked blocks 500. For example, as shown in FIG. 12, in some embodiments, while operating the glass manufacturing apparatus 100, as the front face 303 of the electrode assembly 301 continues to wear (e.g., degrade) during a duration of time, one or more additional blocks 513, 514, 515 can be added to replace and replenish structure of the electrode assembly 301. As will be appreciated, in some embodiments, the process of adding one or more additional blocks can be performed one time or a plurality of times while operating the glass manufacturing apparatus 100 to selectively and continually replace and replenish structure of the electrode assembly 301 as the front face 303 of the electrode assembly 301 wears and degrades.

[0076] Additionally, as shown in **FIG. 5**, in some embodiments, the frames **561**, **562** can include a fastener **575** operable to selectively apply the clamping force. For example, various embodiments of exemplary fasteners are provided in **FIGS. 15-17** with respect to frame **561** with the understanding that one or more fasteners, including fasteners not explicitly disclosed, can be provided in further embodiments to selectively and independently apply the clamping force to each of the frames **561**, **562** without departing from the scope of the disclosure.

[0077] As shown in **FIG. 15**, in some embodiments, the fastener **575** can include a bolt **701** and a nut **702**. In some embodiments, the bolt **701** and the nut **702** can mechanically connect a first portion **561a** and a second portion **561b** of the frame **561**. For example, in some embodiments, the bolt **701** and the nut **702** can connect a first bracket **576** of the first portion **561a** of frame **561** with a second bracket **577** of the second portion **561b** of frame **561**. Accordingly, in some embodiments, operation (e.g., loosening or tightening) of the nut **702** with respect to the bolt **701** can respectively increase or decrease a distance “**d**” between the first portion **561** and the second portion **561b** of the frame **561**.

[0078] As shown in **FIG. 16**, in some embodiments, the fastener **575** can include a hook **703** and a lever **704**. In some embodiments, the hook **703** and the lever **704** can mechanically connect the first portion **561a** and the second portion **561b** of the frame **561**. For example, in some embodiments, the lever **704** and the hook **703** can connect the first bracket **576** of the first portion **561a** of frame **561** with the second bracket **577** of the second portion **561b** of frame **561**. Accordingly, in some embodiments, operation (e.g., rotation along path **705**) of the lever **704** with respect to the hook **703** can respectively decrease or increase the distance “**d**” between the first portion **561** and the second portion **561b** of the frame **561**.

[0079] As shown in **FIG. 17**, in some embodiments, the fastener **575** can include a tension spring **706**. In some embodiments, the tension spring **706** can mechanically connect the first portion **561a** and the second portion **561b** of the frame **561**. For example, in some embodiments, the tension spring **706** can connect the first bracket **576** of the first portion **561a** of frame **561** with the second bracket **577** of the second portion **561b** of frame **561**. Accordingly, in some embodiments, the tension spring **706** can impart a compressive force with respect to the first bracket **576** and the

second bracket **577** that can decrease the distance “**d**” between the first portion **561** and the second portion **561b** of the frame **561**. Conversely, in some embodiments, opposition of the force of the tension spring **706** with respect to the first bracket **576** and the second bracket **577** that can increase the distance “**d**” between the first portion **561** and the second portion **561b** of the frame **561**. In some embodiments, decreasing the distance “**d**” can increase (e.g., apply) the clamping force on the stacked blocks **500**, and increasing the distance “**d**” can decrease (e.g., remove) the clamping force from the stacked blocks **500**.

[0080] For example, as shown in **FIG. 8**, in some embodiments, frame **561** can apply the clamping force to the stacked blocks **500** to hold the plurality of blocks **500** in the stacked configuration. Additionally, in some embodiments, the clamping force of frame **562** can be removed and frame **562** can then be translated in direction **566** to be positioned to receive additional blocks **510**, **511**, **512**. By employing at least two independently movable frames **561**, **562**, in some embodiments, at least one frame (e.g., frame **561**) can apply the clamping force and hold the plurality of blocks **500** in the stacked configuration while the clamping force of at least one other frame (e.g., frame **562**) can be removed to permit the un-clamped frame **562** to be translated relative to the stacked blocks **500** in direction **566**. As shown in **FIG. 9**, once the additional blocks **510**, **511**, **512** have been added to the stack of blocks **500**, the clamping force of frame **562** can then be applied to hold the additional blocks **510**, **511**, **512** in the stacked configuration with the existing blocks **501**, **503**, **505**, **507**, **508**, **509**, thereby defining the plurality of blocks **500** of the electrode assembly **301**. Moreover, in some embodiments, once the clamping force of frame **562** has been applied, the clamping force of frame **561** can then be removed to permit the un-clamped frame **561** to be translated relative to the stacked blocks **500** in direction **566**. That is, in some embodiments, the frames **561**, **562** can be employed to selectively apply and/or remove the clamping force on the stacked blocks **500** of the electrode assembly **301** independent of each other and/or simultaneously with each other. In some embodiments, at least one frame **561**, **562** can provide the clamping force to hold the blocks **500** in the stacked configuration and to ensure electrical contact between faces of the blocks **500** during, for example, an entire duration of time defining operation of the glass manufacturing apparatus **100**.

[0081] In some embodiments, one or more clamped frames (e.g., frames 561, 562 in FIG. 6) can apply the clamping force to hold the blocks 500 in the stacked configuration while the electrode assembly 301 is stationary. Likewise, in some embodiments, the clamped frames (e.g., frames 561, 562 in FIG. 6 and FIG. 7) can be translated relative to the first opening 403 along the adjustment path 565 extending in direction “Z” to translate the front face 303 of the electrode assembly 301 along the adjustment path 565 in direction “Z” to compensate for structural degradation of the front face 303 of the electrode assembly 301 caused by wear while operating the glass manufacturing apparatus 100. Similarly, in some embodiments, once the additional blocks 510, 511, 512 are added (as schematically represented in FIG. 8 and FIG. 9), the clamped frames (e.g., frames 561, 562 in FIG. 10) can be translated relative to the first opening 403 along the adjustment path 565 extending in direction “Z” to translate the front face 303 of the electrode assembly 301 along the adjustment path 565 in direction “Z” to compensate for further structural degradation of the front face 303 of the electrode 301 assembly caused by wear while operating the glass manufacturing apparatus 100.

[0082] As shown in FIG. 11, in some embodiments, for example, after translating the front face 303 of the electrode assembly 301 along the adjustment path 565 in direction “Z” to compensate for further structural degradation of the front face 303 of the electrode assembly 301 caused by wear while operating the glass manufacturing apparatus 100, the clamping force of frame 562 can be removed again and frame 562 can then be translated in direction 566 to be positioned to receive additional blocks 513, 514, 515 while frame 561 can apply the clamping force and hold the plurality of blocks 500 in the stacked configuration. As shown in FIG. 12, once the additional blocks 513, 514, 515 have been added to the stack of blocks 500, the clamping force of frame 562 can then be applied to hold the additional blocks 513, 514, 515 in the stacked configuration with the existing blocks 507, 508, 509, 510, 511, 512 thereby defining the plurality of blocks 500 of the electrode assembly 301. As noted previously, in some embodiments, once the clamping force of frame 562 has been applied, the clamping force of frame 561 can then be removed to permit the unclamped frame 561 to be translated relative to the stacked blocks 500 while frame 562 applies the clamping force to hold the blocks 500 in the stacked configuration.

Accordingly, in some embodiments, the clamped frames (e.g., frames **561**, **562** in **FIG. 12**) can then be translated relative to the first opening **403** along the adjustment path **565** extending in direction “Z” to translate the front face **303** of the electrode assembly **301** along the adjustment path **565** in direction “Z” to compensate for further structural degradation of the front face **303** of the electrode assembly **301** caused by wear while operating the glass manufacturing apparatus **100**. Unless otherwise noted, it is to be understood that the process of clamping and unclamping the frames **561**, **562**, translating the electrode assembly **301** to compensate for wear, and adding additional blocks to the stack of blocks **500** can be performed (e.g., repeated) a plurality of times before, during, or after operation of the glass manufacturing apparatus **100** without departing from the scope of the disclosure.

[0083] An exemplary block **525** is shown in **FIG. 13** with the understanding that, in some embodiments, one or more of the plurality of blocks **500** can be identical to the exemplary block **525**. Moreover, in some embodiments, one or more of the plurality of blocks **500** can include one or more features that are the same as or similar to the features of the exemplary block **525** as well as one or more features that differ from features of the exemplary block **525**, without departing from the scope of the disclosure. Likewise, in some embodiments, one or more of the plurality of blocks **500** can be provided as partial (e.g., one-quarter, one-third, half, two-thirds, three-quarters, etc.) blocks of exemplary block **525**. For example, in some embodiments, the block **525** can include a first surface **525d**, **525e** extending from a first end **525a** of the block **525** to a second end **525b** of the block **525**. In some embodiments, the block **525** can include a second surface **525c** opposing the first surface **525d**, **525e** and extending from the first end **525a** of the block **525** to the second end **525b** of the block **525**. In some embodiments, a third surface **525f** of the block **525** and an opposing fourth surface **525g** of the block **525** can define respective outer boundaries of the block **525** within the first surface **525d**, **525e**, the second surface **525c**, the first end **525a**, and the second end **525b**. In some embodiments, the first surface **525d**, **525e** can define a non-planar boundary of the block **525**. For example, in some embodiments, a first planar portion **525d** of the surface can intersect a second planar portion **525e** of the surface at a non-zero angle to define the non-planar boundary of the block **525**. In some embodiments, at least one of the first planar portion **525d** and the second planar portion **525e** can extend at a non-perpendicular angle relative to the

X-Y plane. Although not explicitly illustrated, it is to be understood that, in some embodiments, one or more planar and/or non-planar (e.g., curved, stepped, undulating, angled) portions of the first surface **525d**, **525e** can be provided to define the non-planar (e.g., curved, stepped, undulating, angled) boundary of the block **525** without departing from the scope of the disclosure.

[0084] Without intending to be bound by theory, it is believed that the non-planar boundary of the first surface **525d**, **525e** of the block **525** can provide better electrical contact between adjacent, abutting blocks than, for example, a comparable planar boundary. Moreover, in some embodiments, structural stability of the stack of blocks **500** can also be increased based at least in part on the offset (e.g., staggered) stacking of the blocks and the non-planar boundary defining one or more interfaces between immediately adjacent blocks as the electrode assembly **301** is provided in a stationary position and/or as the electrode assembly **301** is translated during operation of the glass manufacturing apparatus **100** as compared to, for example, a stack of blocks having comparable planar boundaries.

[0085] For example, **FIG. 14** shows an exemplary embodiment of a plurality of blocks **500** stacked along the first axis “X” and offset (e.g., staggered) along the third axis “Z” in accordance with embodiments of the disclosure. A portion of electrode assembly **301** is provided including block **501**, half-block **502**, and blocks **507**, **510** and **513**. In some embodiments, block **501** can include a first end **501a**, a second end **501b**, a first surface **501d**, **501e** defining the non-planar boundary of the block **501**, a second surface **501c**, and a third surface **501f** as described with respect to the exemplary block **525** (**FIG. 13**). Likewise, in some embodiments, half-block **502** can include a first end **502a**, a second end **502b**, a first surface **502e** defining a portion of the non-planar boundary of the block **502**, a second surface **502c**, and a third surface **502f**. Similarly, in some embodiments, blocks **507**, **510**, **513** can include a first end **507a**, **510a**, **513a**, a second end **507b**, **510b**, **513b**, a first surface **507d**, **507e**, **510d**, **510e**, **513d**, **513e** defining the non-planar boundary of the blocks **507**, **510**, **513**, a second surface **507c**, **510c**, **513c**, and a third surface **507f**, **510f**, **513f** as described with respect to the exemplary block **525** (**FIG. 13**).

[0086] In some embodiments, a first dimension “d1” of block **501** defined along the third axis “Z” from end **501a** to end **501b** can be greater than a second

dimension “**d2**” of block **502** defined along the third axis “**Z**” from end **502a** to end **502b**. Additionally, in some embodiments, end **501b** of the first block **501** can define a first portion of the first face **303** of the electrode assembly **301**, and end **502a** of the second block **502** can define a second portion of the first face **303** of the electrode assembly **301**. As noted, in some embodiments, at least a portion of the first face **303** can define a planar surface of the electrode assembly **301**. In some embodiments, a third dimension “**d3**” of block **507** defined along the third axis “**Z**” from end **507a** to end **507b** can be greater than the second dimension “**d3**” of block **502**. In some embodiments, the first dimension “**d1**” of block **501** can be equal to the third dimension “**d3**” of block **507**.

[0087] In some embodiments, the portion **501e** of the surface defining the non-planar boundary of block **501** can face the portion **502e** of the surface defining at least a portion of the non-planar boundary of half-block **502**. For example, in some embodiments, the portion **501e** of the surface defining the non-planar boundary of block **501** can abut the portion **502e** of the surface defining at least a portion of the non-planar boundary of half-block **502** at an interface **521**. Likewise, in some embodiments, the portion **501d** of the surface defining the non-planar boundary of block **501** can face the portion **507d** of the surface defining the non-planar boundary of block **507**. For example, in some embodiments, the portion **501d** of the surface defining the non-planar boundary of block **501** can abut the portion **507d** of the surface defining the non-planar boundary of block **507** at an interface **571**. Similarly, in some embodiments, the portion **507e** of the surface defining the non-planar boundary of block **507** can face the portion **510e** of the surface defining the non-planar boundary of block **510**. For example, in some embodiments, the portion **507e** of the surface defining the non-planar boundary of block **507** can abut the portion **510e** of the surface defining the non-planar boundary of block **510** at an interface. It is to be understood that the staggered pattern of the stacked blocks **500** can be repeated with any number of blocks and/or partial blocks without departing from the scope of the disclosure.

[0088] Moreover, in some embodiments, the portion **513d** of the surface defining the non-planar boundary of block **513** can face the portion **510d** of the surface defining the non-planar boundary of block **510**. For example, in some embodiments, the portion **513d** of the surface defining the non-planar boundary of

block **513** can be positioned (e.g., added to the stack of blocks **500**) to abut the portion **510d** of the surface defining the non-planar boundary of block **510** at an interface (not shown). Additionally, in some embodiments, end **501b** of block **501** and end **502a** of half-block **502** can be coplanar with the planar surface defining the front face **303** of the electrode **301**. In some embodiments, end **501a** of block **501** can face (e.g., abut) end **510b** of block **510**, end **502b** of half-block **502** can face (e.g., abut) end **507a** of block **507** at interface **527**, and end **513a** of block **513** can face (e.g., be positioned to abut) end **507b** of block **507**. Accordingly, in some embodiments, the interface (e.g., interfaces **521**, **527**, **571**) between abutting surfaces of immediately adjacent stacked blocks **500** can provide an electrical connection between the plurality of blocks **500** defining the electrode assembly **301**. Likewise, in some embodiments, the process of stacking and/or adding blocks can be repeated to continually replace and replenish depleted electrode material with new electrode material without interrupting the manufacturing process.

**[0089]** Embodiments and the functional operations described herein can be implemented in digital electronic circuitry, or in computer software, firmware, or hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. Embodiments described herein can be implemented as one or more computer program products, i.e., one or more modules of computer program instructions encoded on a tangible program carrier for execution by, or to control the operation of, data processing apparatus. The tangible program carrier can be a computer readable medium. The computer readable medium can be a machine-readable storage device, a machine-readable storage substrate, a memory device, or a combination of one or more of them.

**[0090]** The term “processor” or “controller” can encompass all apparatus, devices, and machines for processing data, including by way of example a programmable processor, a computer, or multiple processors or computers. The processor can include, in addition to hardware, code that creates an execution environment for the computer program in question, e.g., code that constitutes processor firmware, a protocol stack, a database management system, an operating system, or a combination of one or more of them.

**[0091]** A computer program (also known as a program, software, software application, script, or code) can be written in any form of programming language, including compiled or interpreted languages, or declarative or procedural languages, and it can be deployed in any form, including as a standalone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A computer program does not necessarily correspond to a file in a file system. A program can be stored in a portion of a file that holds other programs or data (e.g., one or more scripts stored in a markup language document), in a single file dedicated to the program in question, or in multiple coordinated files (e.g., files that store one or more modules, sub programs, or portions of code). A computer program can be deployed to be executed on one computer or on multiple computers that are located at one site or distributed across multiple sites and interconnected by a communication network.

**[0092]** The processes described herein can be performed by one or more programmable processors executing one or more computer programs to perform functions by operating on input data and generating output. The processes and logic flows can also be performed by, and apparatus can also be implemented as, special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application specific integrated circuit) to name a few.

**[0093]** Processors suitable for the execution of a computer program include, by way of example, both general and special purpose microprocessors, and any one or more processors of any kind of digital computer. Generally, a processor will receive instructions and data from a read only memory or a random-access memory or both. The essential elements of a computer are a processor for performing instructions and one or more data memory devices for storing instructions and data. Generally, a computer will also include, or be operatively coupled to receive data from or transfer data to, or both, one or more mass storage devices for storing data, e.g., magnetic, magneto optical disks, or optical disks. However, a computer need not have such devices. Moreover, a computer can be embedded in another device, e.g., a mobile telephone, a personal digital assistant (PDA), to name just a few.

**[0094]** Computer readable media suitable for storing computer program instructions and data include all forms data memory including nonvolatile memory, media and memory devices, including by way of example semiconductor memory

devices, e.g., EPROM, EEPROM, and flash memory devices; magnetic disks, e.g., internal hard disks or removable disks; magneto optical disks; and CD ROM and DVD-ROM disks. The processor and the memory can be supplemented by, or incorporated in, special purpose logic circuitry.

**[0095]** To provide for interaction with a user, embodiments described herein can be implemented on a computer having a display device, e.g., a CRT (cathode ray tube) or LCD (liquid crystal display) monitor, and the like for displaying information to the user and a keyboard and a pointing device, e.g., a mouse or a trackball, or a touch screen by which the user can provide input to the computer. Other kinds of devices can be used to provide for interaction with a user as well; for example, input from the user can be received in any form, including acoustic, speech, or tactile input.

**[0096]** Embodiments described herein can be implemented in a computing system that includes a back end component, e.g., as a data server, or that includes a middleware component, e.g., an application server, or that includes a front end component, e.g., a client computer having a graphical user interface or a Web browser through which a user can interact with implementations of the subject matter described herein, or any combination of one or more such back end, middleware, or front end components. The components of the system can be interconnected by any form or medium of digital data communication, e.g., a communication network. Examples of communication networks include a local area network (“LAN”) and a wide area network (“WAN”), e.g., the Internet.

**[0097]** The computing system can include clients and servers. A client and server are generally remote from each other and typically interact through a communication network. The relationship of client and server arises by virtue of computer programs running on the respective computers and having a client-server relationship to each other.

**[0098]** It will be appreciated that the various disclosed embodiments may involve particular features, elements or steps that are described in connection with that particular embodiment. It will also be appreciated that a particular feature, element or step, although described in relation to one particular embodiment, may be interchanged or combined with alternate embodiments in various non-illustrated combinations or permutations.

[0099] It is also to be understood that, as used herein the terms “the,” “a,” or “an,” mean “at least one,” and should not be limited to “only one” unless explicitly indicated to the contrary. Likewise, a “plurality” is intended to denote “more than one.”

[00100] Ranges can be expressed herein as from “about” one particular value, and/or to “about” another particular value. When such a range is expressed, embodiments include from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent “about,” it will be understood that the particular value forms another embodiment. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

[00101] The terms “substantial,” “substantially,” and variations thereof as used herein are intended to note that a described feature is equal or approximately equal to a value or description.

[00102] Unless otherwise expressly stated, it is in no way intended that any method set forth herein be construed as requiring that its steps be performed in a specific order. Accordingly, where a method claim does not actually recite an order to be followed by its steps or it is not otherwise specifically stated in the claims or descriptions that the steps are to be limited to a specific order, it is no way intended that any particular order be inferred.

[00103] While various features, elements or steps of particular embodiments may be disclosed using the transitional phrase “comprising,” it is to be understood that alternative embodiments, including those that may be described using the transitional phrases “consisting” or “consisting essentially of,” are implied. Thus, for example, implied alternative embodiments to an apparatus that comprises A+B+C include embodiments where an apparatus consists of A+B+C and embodiments where an apparatus consists essentially of A+B+C.

[00104] It will be apparent to those skilled in the art that various modifications and variations can be made to the present disclosure without departing from the spirit and scope of the appended claims. Thus, it is intended that the present disclosure cover the modifications and variations of the embodiments herein provided they come within the scope of the appended claims and their equivalents.

**[00105]** It should be understood that while various embodiments have been described in detail with respect to certain illustrative and specific embodiments thereof, the present disclosure should not be considered limited to such, as numerous modifications and combinations of the disclosed features are possible without departing from the scope of the following claims.

## CLAIMS

What is claimed is:

1. An electrode assembly comprising:  
a plurality of blocks stacked along a first axis in a first direction;  
wherein the plurality of blocks spans a first distance along the first axis, a second distance along a second axis in a second direction perpendicular to the first direction, wherein the first distance and the second distance define a first face of the electrode assembly, and wherein the plurality of blocks span a third distance from the first face of the electrode assembly to a second face of the electrode assembly along a third axis in a third direction perpendicular to the first direction and the second direction; and  
wherein a first dimension of a first block of the plurality of blocks defined along the third axis from a first end of the first block to a second end of the first block is greater than a second dimension of a second block of the plurality of blocks defined along the third axis from a first end of the second block to a second end of the second block.
2. The electrode assembly of claim 1, wherein the first end of the first block defines a first portion of the first face, and wherein the first end of the second block defines a second portion of the first face.
3. The electrode assembly of claim 1 or claim 2, wherein the first face defines a planar surface of the electrode assembly.
4. The electrode assembly of any one of claims 1-3, wherein the first block comprises a first surface extending from the first end of the first block to the second end of the first block, and wherein the first surface defines a non-planar boundary of the first block.
5. The electrode assembly of claim 4, wherein the second block comprises a second surface extending from the first end of the second block to the second end of

the second block, and wherein a first portion of the first surface of the first block faces a portion of the second surface of the second block.

6. The electrode assembly of claim 5, wherein the first portion of the first surface of the first block abuts the portion of the second surface of the second block at a first interface.

7. The electrode assembly of any one of claims 1-6, wherein a third dimension of a third block of the plurality of blocks defined along the third axis from a first end of the third block to a second end of the third block is greater than the second dimension, and wherein the first end of the third block faces the second end of the second block.

8. The electrode assembly of claim 6, wherein the first dimension equals the third dimension.

9. The electrode assembly of claim 7 or claim 8, wherein the third block comprises a third surface extending from the first end of the third block to the second end of the third block, wherein the third surface defines a non-planar boundary of the third block, and wherein a second portion of the first surface of the first block faces a portion of the third surface of the third block.

10. The electrode assembly of claim 9, wherein the first end of the third block abuts the second end of the second block at a second interface, and wherein the second portion of the first surface of the first block abuts the portion of the third surface of the third block at a third interface.

11. The electrode assembly of any one of claims 1-10, further comprising a first frame circumscribing the plurality of blocks along the first axis and the second axis.

12. The electrode assembly of claim 11, wherein the first frame is movable along the third axis.

13. The electrode assembly of claim 11 or claim 12, wherein the first frame applies a first clamping force on the plurality of blocks along at least one of the first axis and the second axis.
14. The electrode assembly of claim 13, wherein the first frame comprises a first fastener oriented to at least one of increase and decrease the first clamping force.
15. The electrode assembly of any one of claims 11-14, further comprising a second frame circumscribing the plurality of blocks along the first axis and the second axis, wherein the second frame is movable along the third axis, wherein the second frame applies a second clamping force on the plurality of blocks along at least one of the first axis and the second axis, wherein the second frame comprises a second fastener oriented to at least one of increase and decrease the second clamping force, and wherein the first frame and the second frame are independently movable along the third axis.
16. An apparatus comprising the electrode assembly of any one of claims 1-15, comprising a vessel comprising at least one wall defining a containment area of the vessel, the at least one wall comprising an aperture defining an opening receiving at least a portion of the electrode assembly.
17. The apparatus of claim 16, wherein the vessel comprises a melting vessel for a glass manufacturing system.
18. The apparatus of claim 16 or claim 17, wherein a position of the electrode assembly is adjustable relative to the opening of the wall.
19. A method of processing material in the vessel of any one of claims 16-18, comprising supplying electrical energy to the electrode assembly and heating the material in the containment area of the vessel with the electrical energy.
20. The method of claim 19, comprising adjusting a position of the electrode assembly relative to the opening of the wall while heating the material.

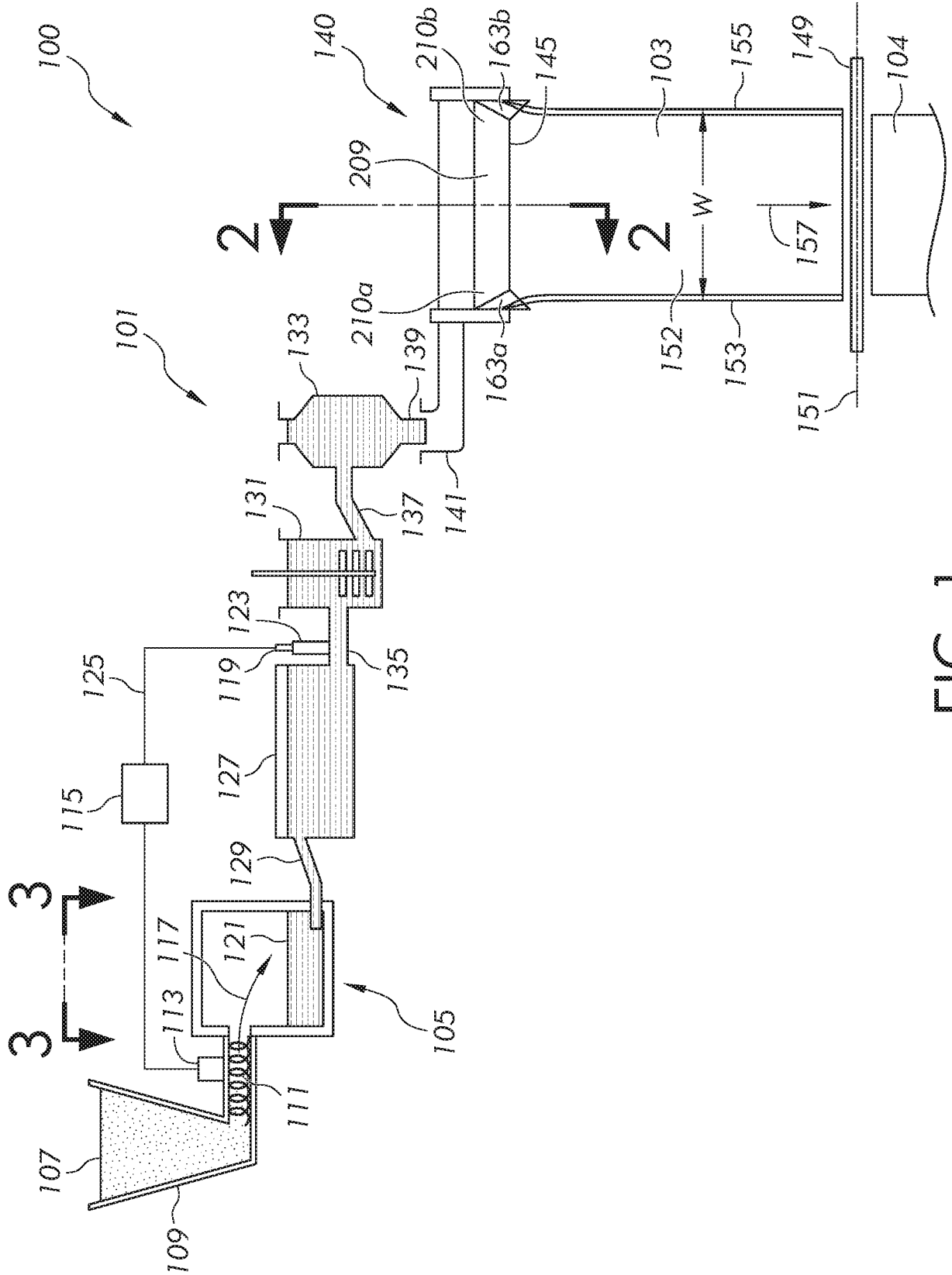
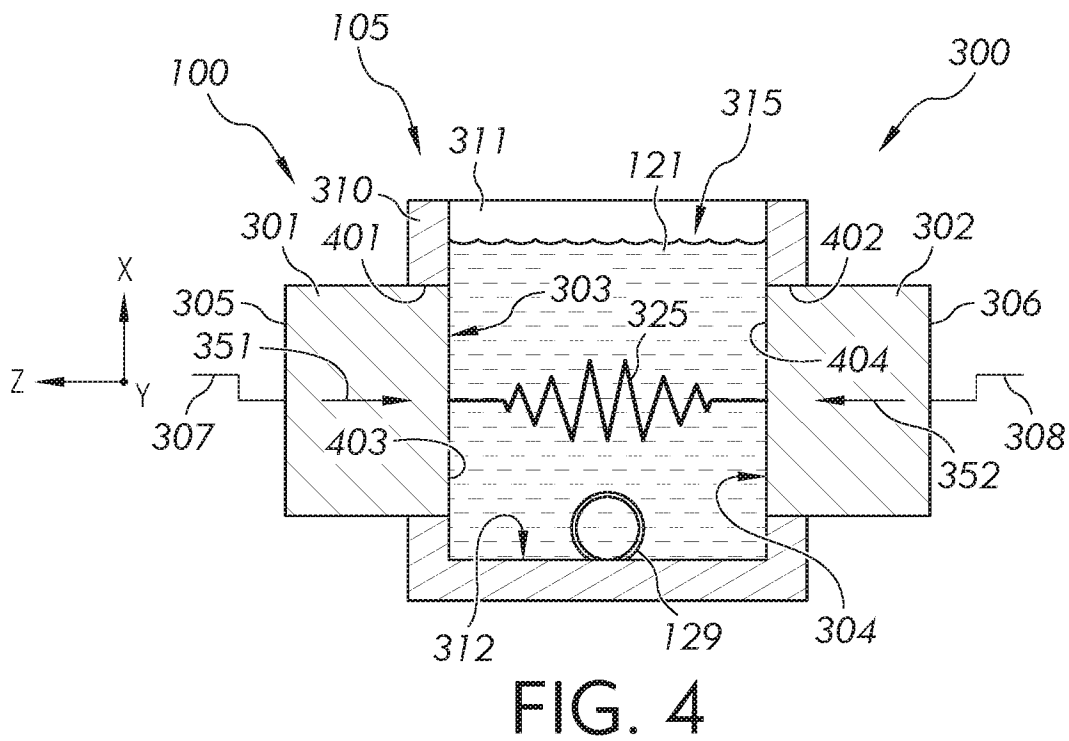
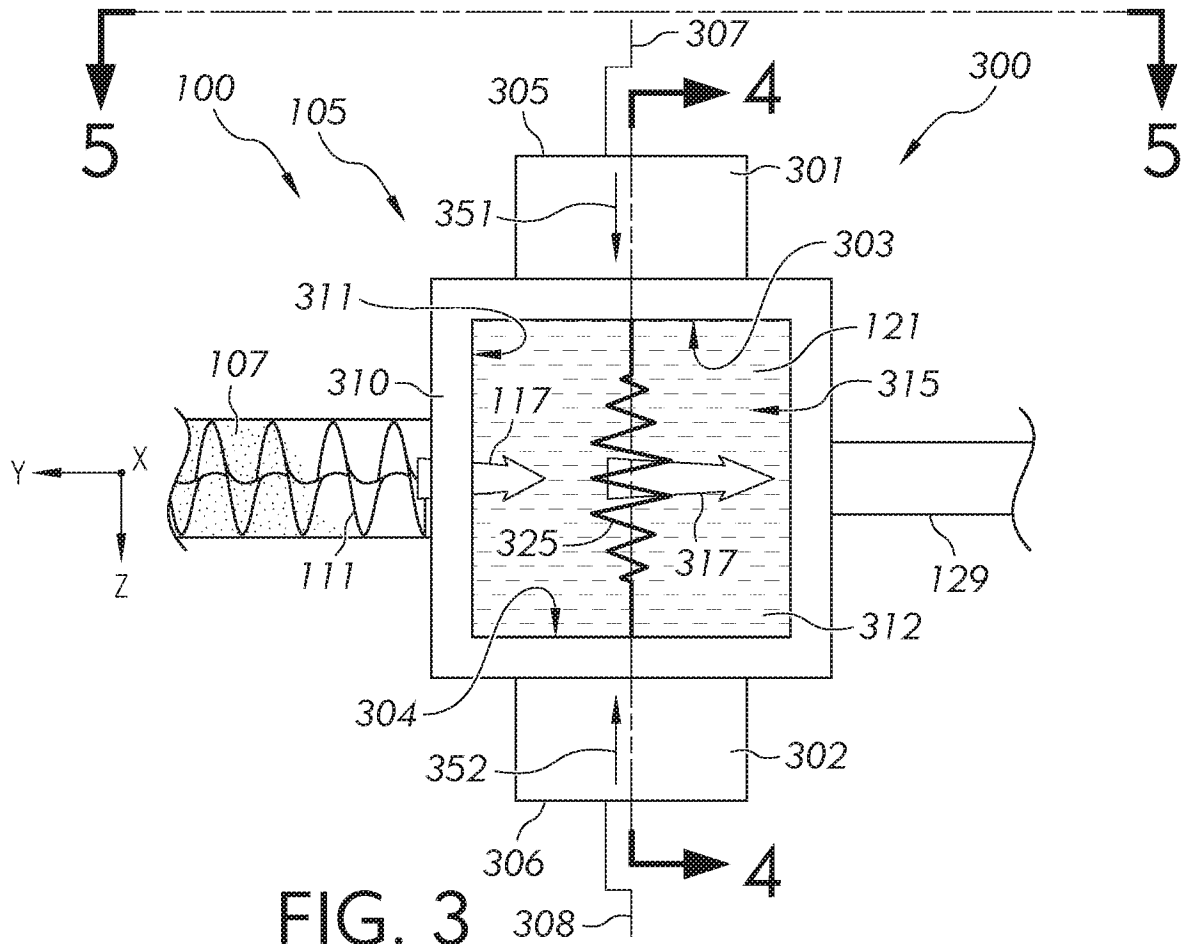


FIG. 1





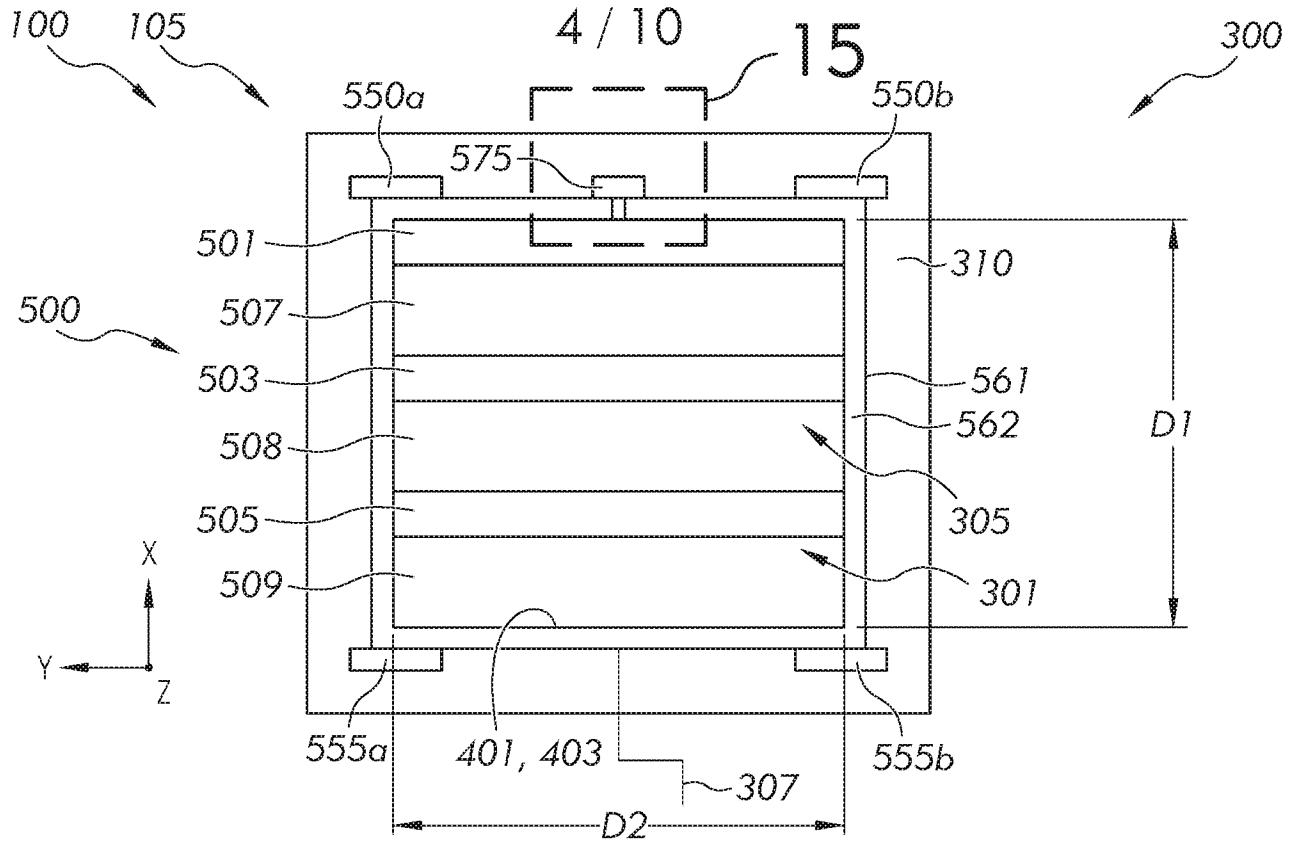


FIG. 5

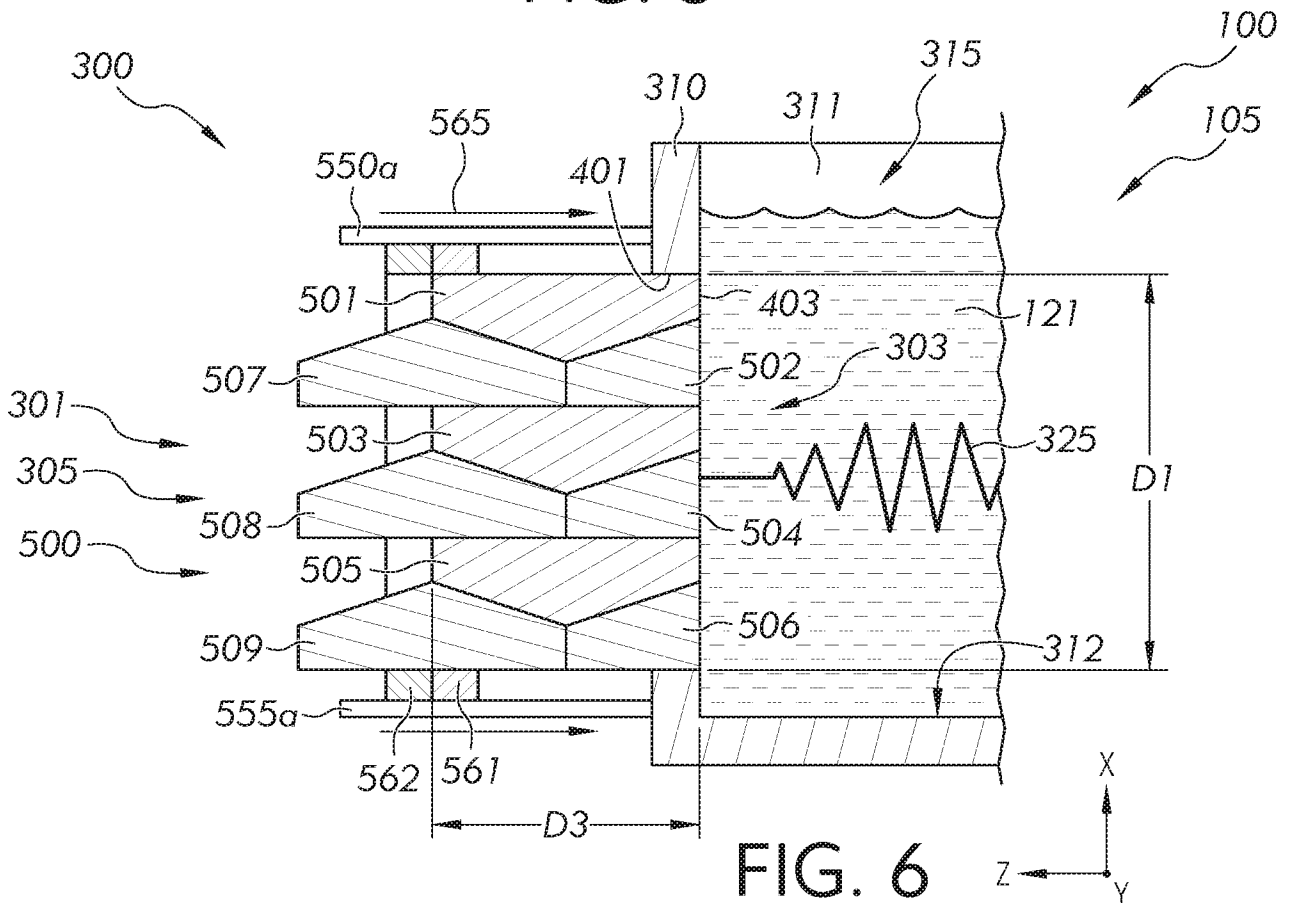
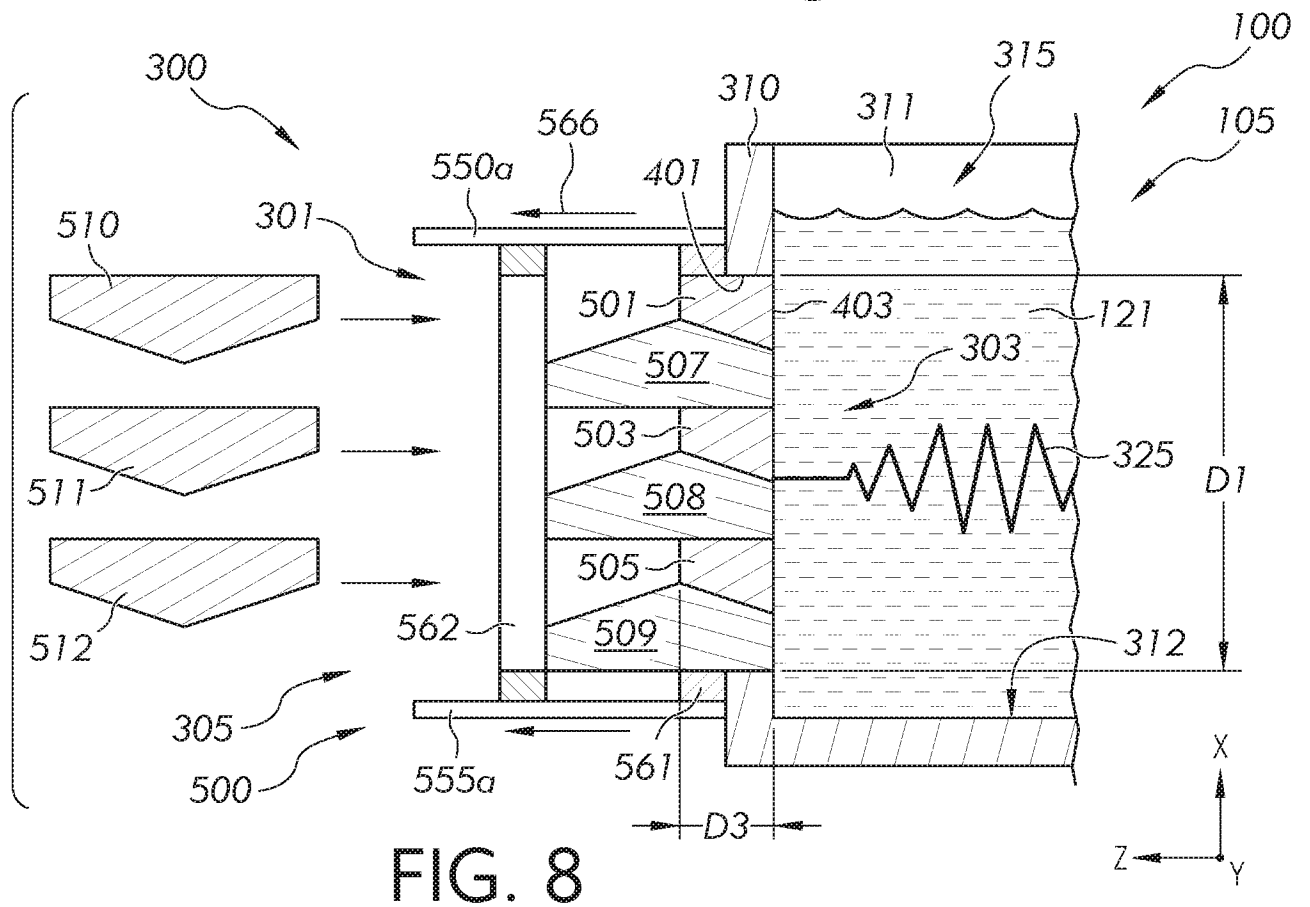
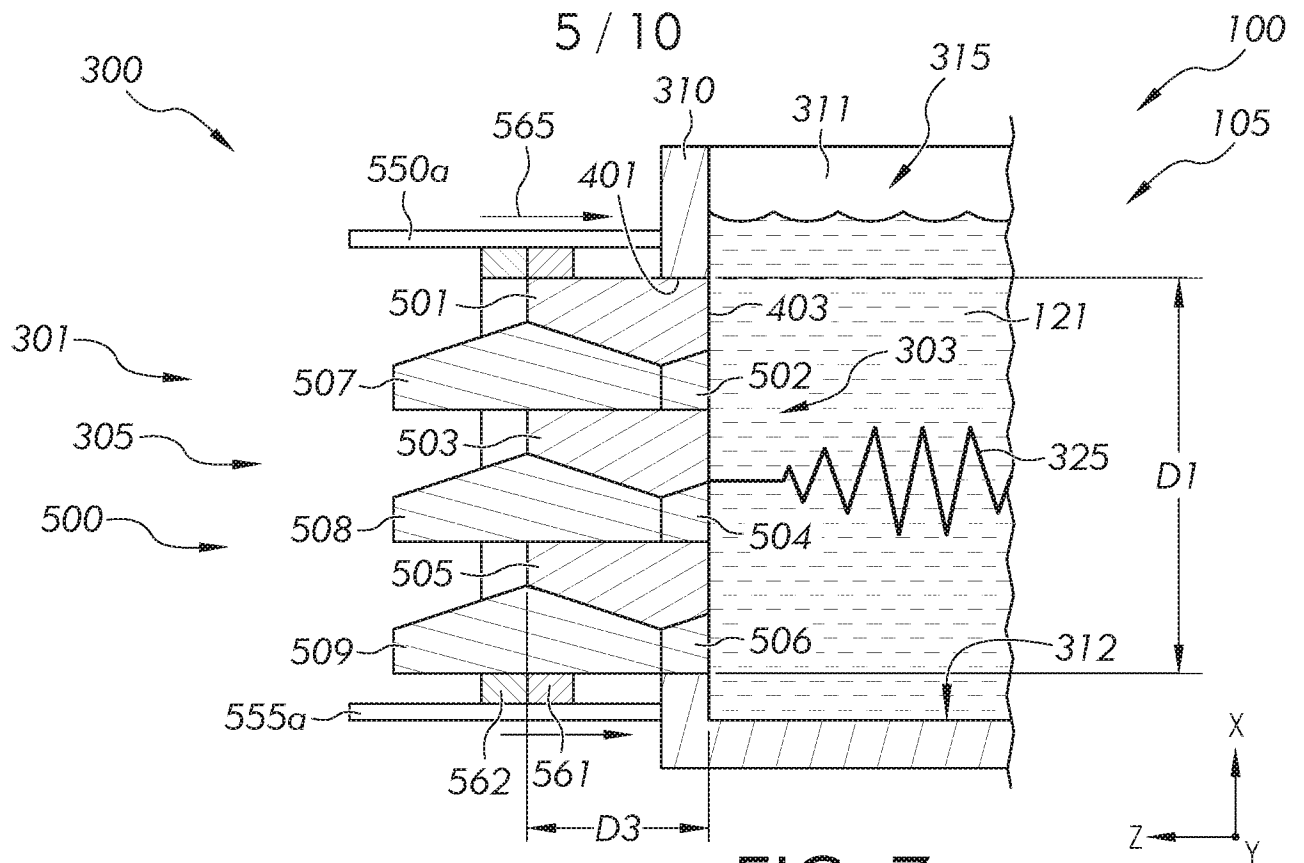


FIG. 6



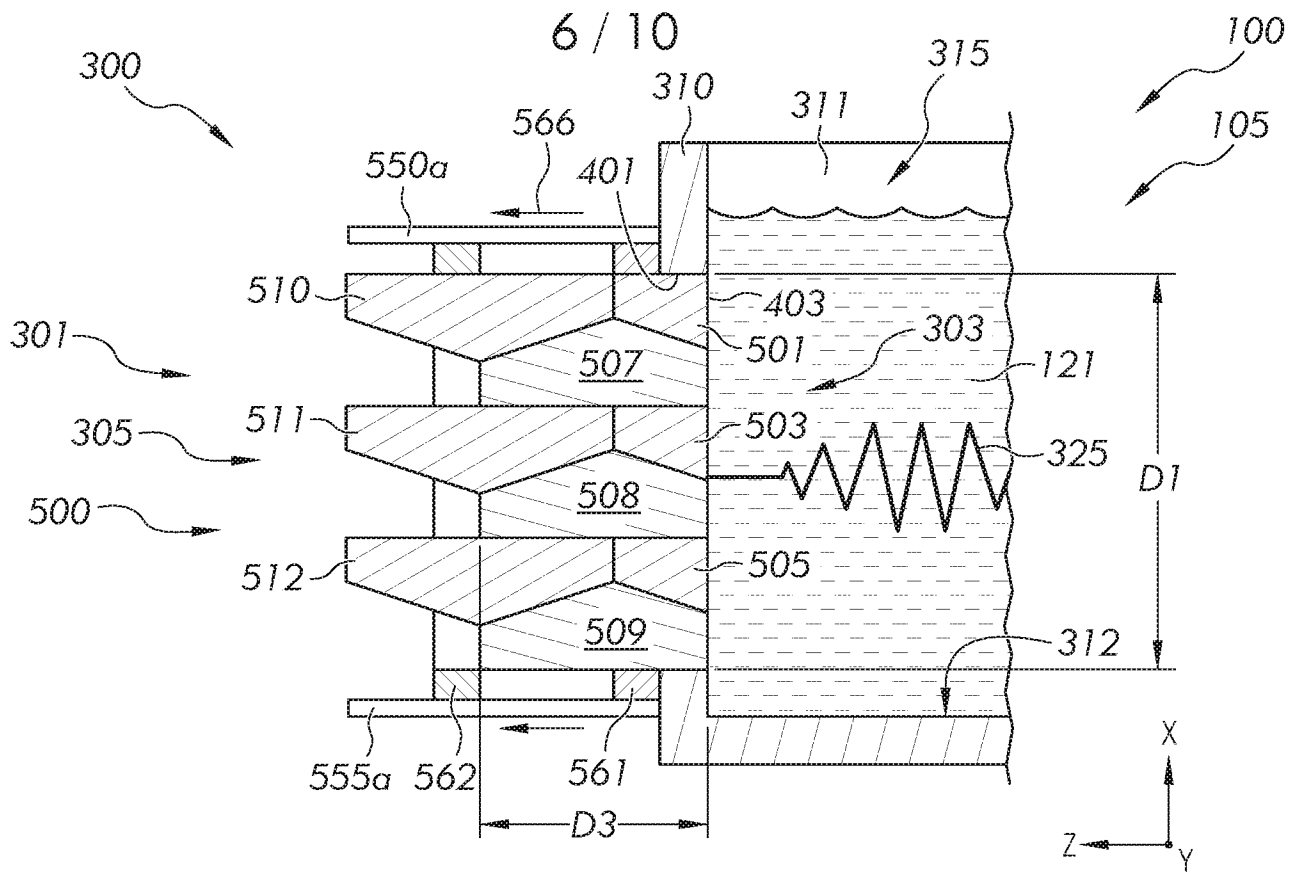


FIG. 9

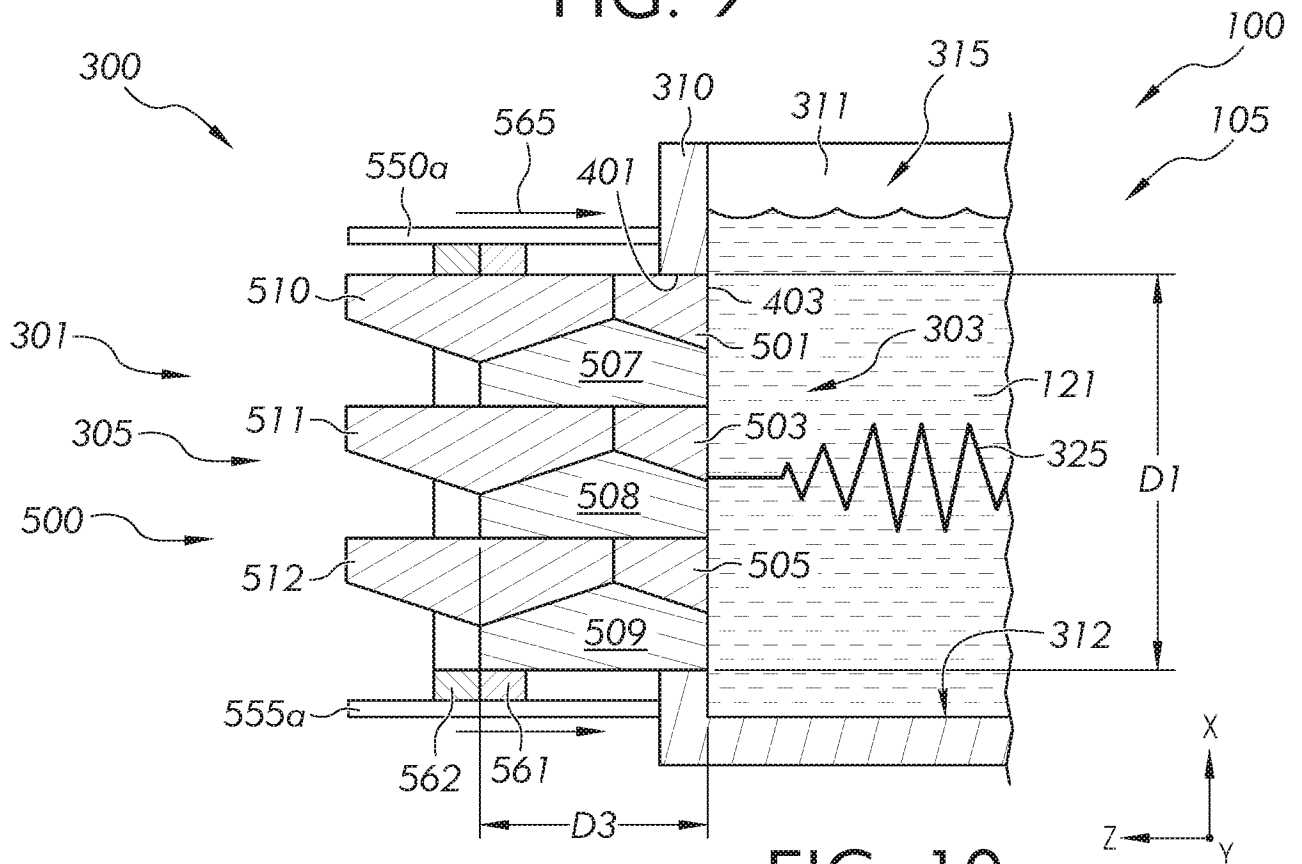


FIG. 10

7 / 10

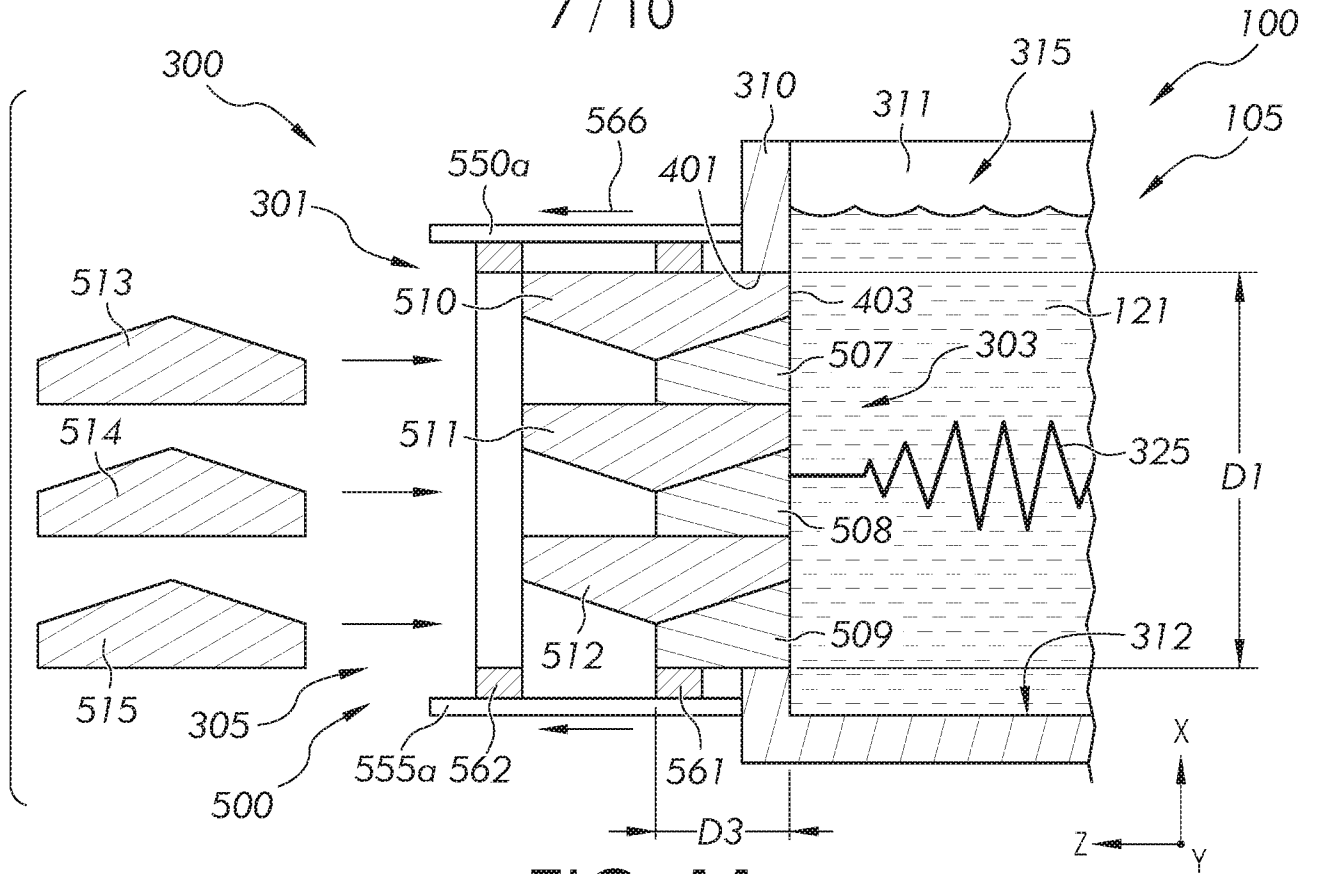


FIG. 11

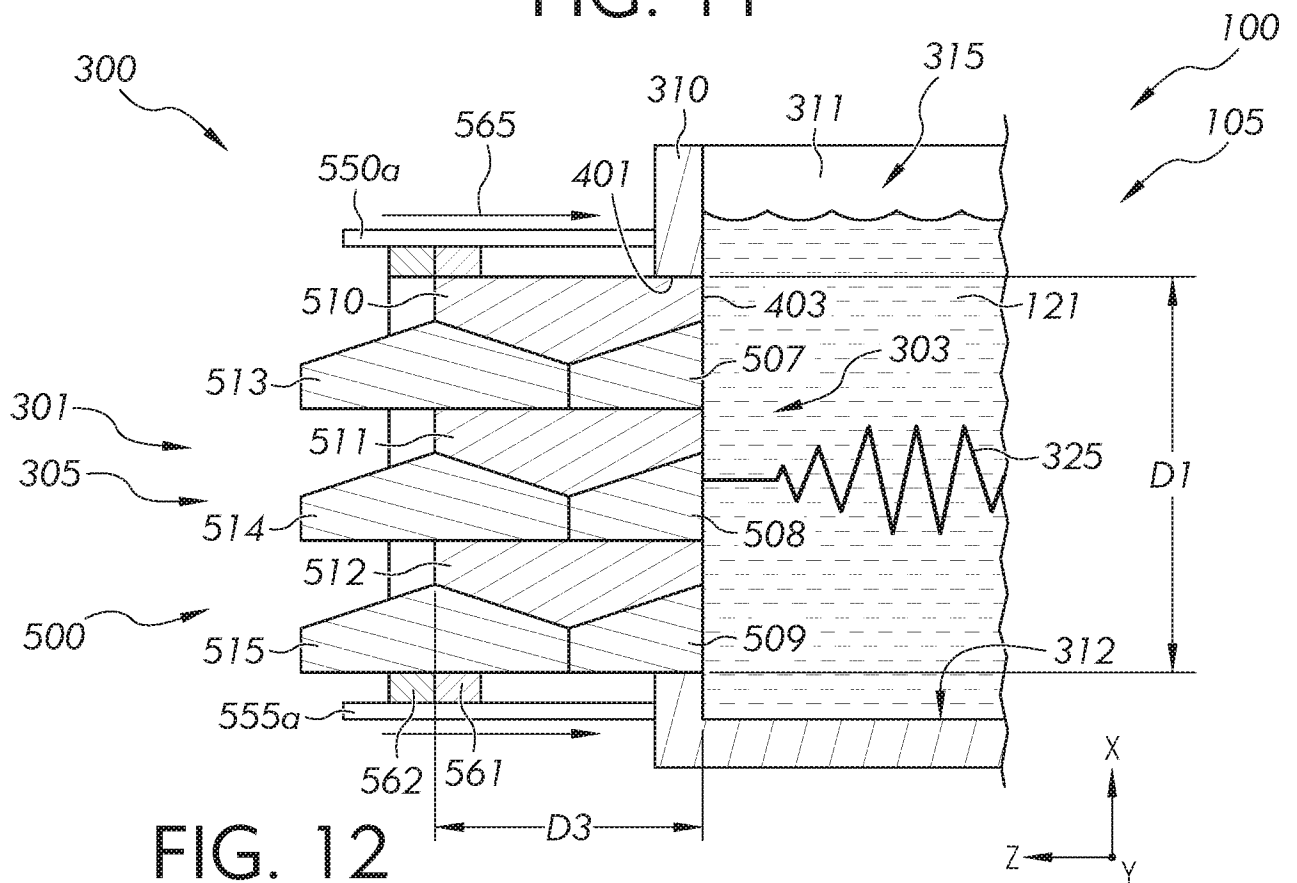


FIG. 12



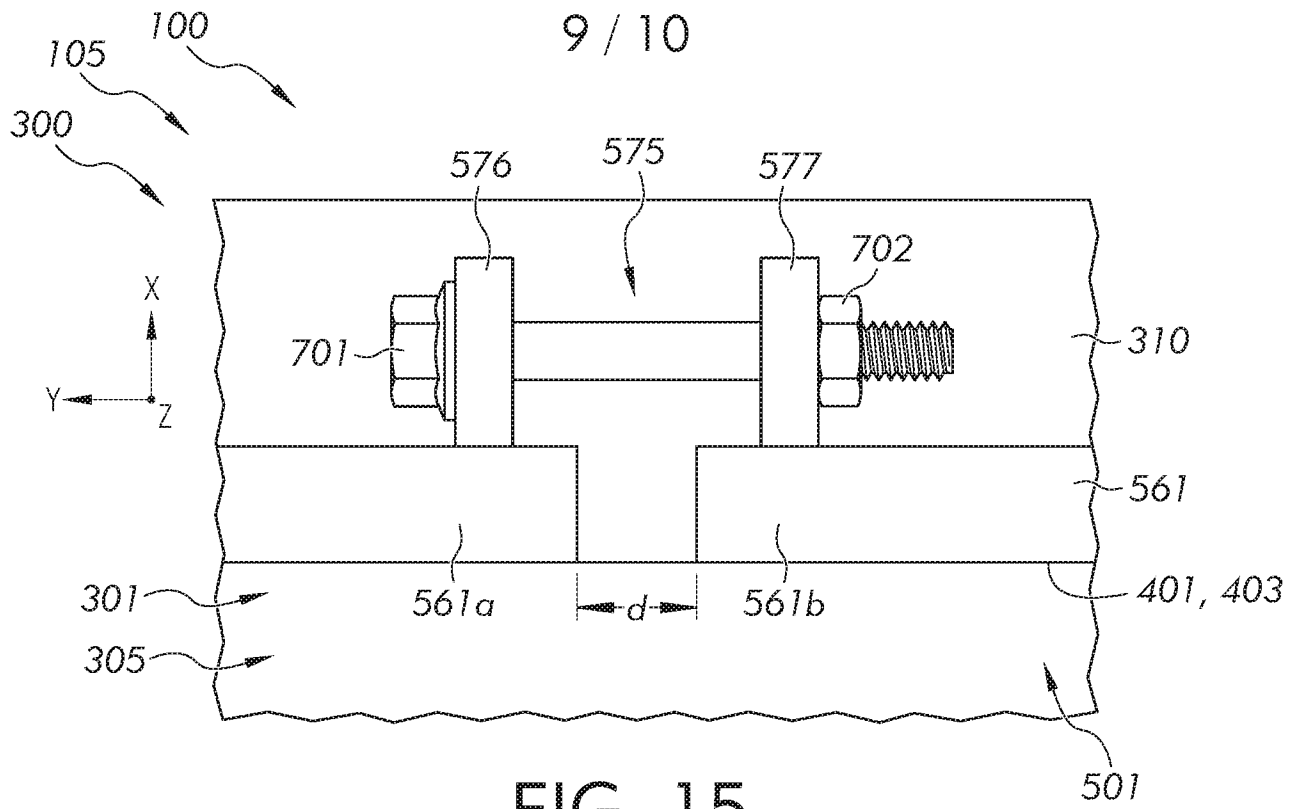


FIG. 15

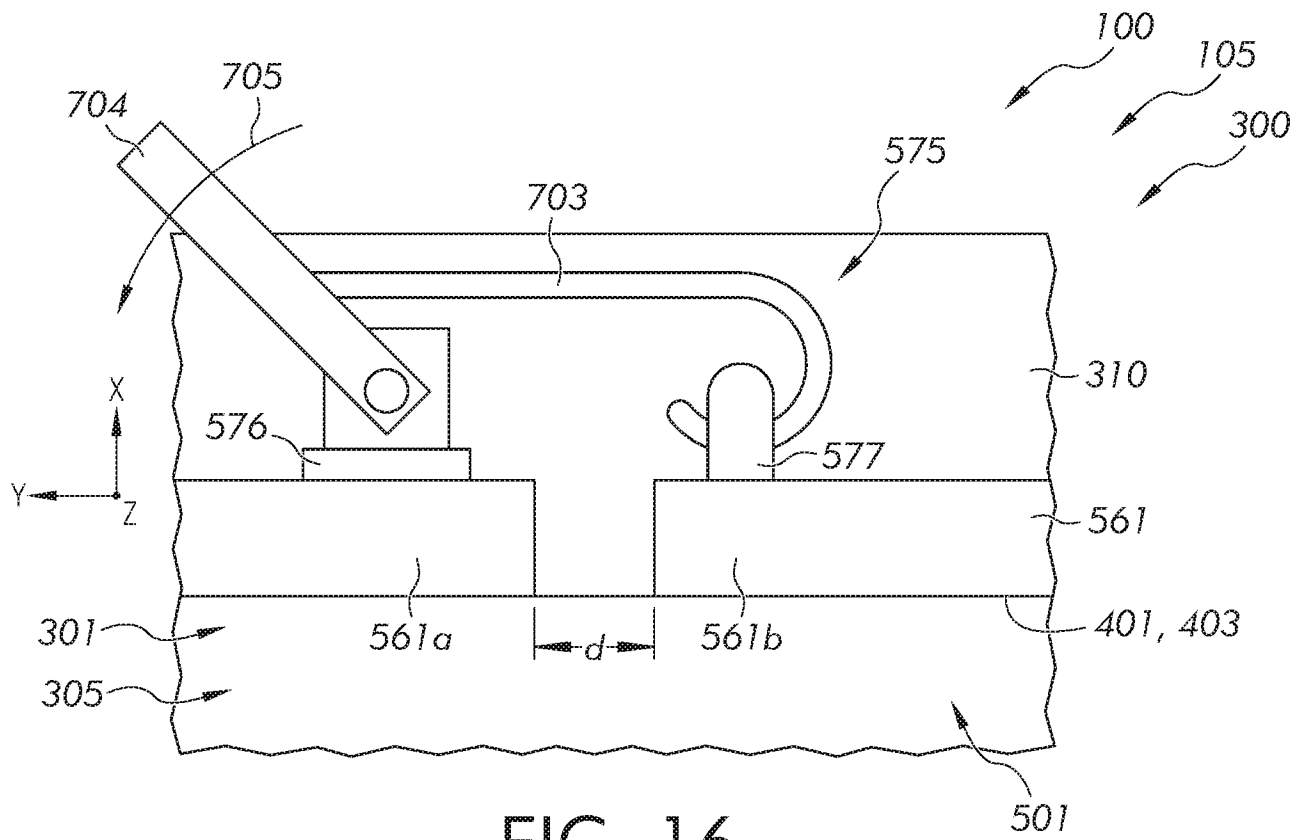


FIG. 16

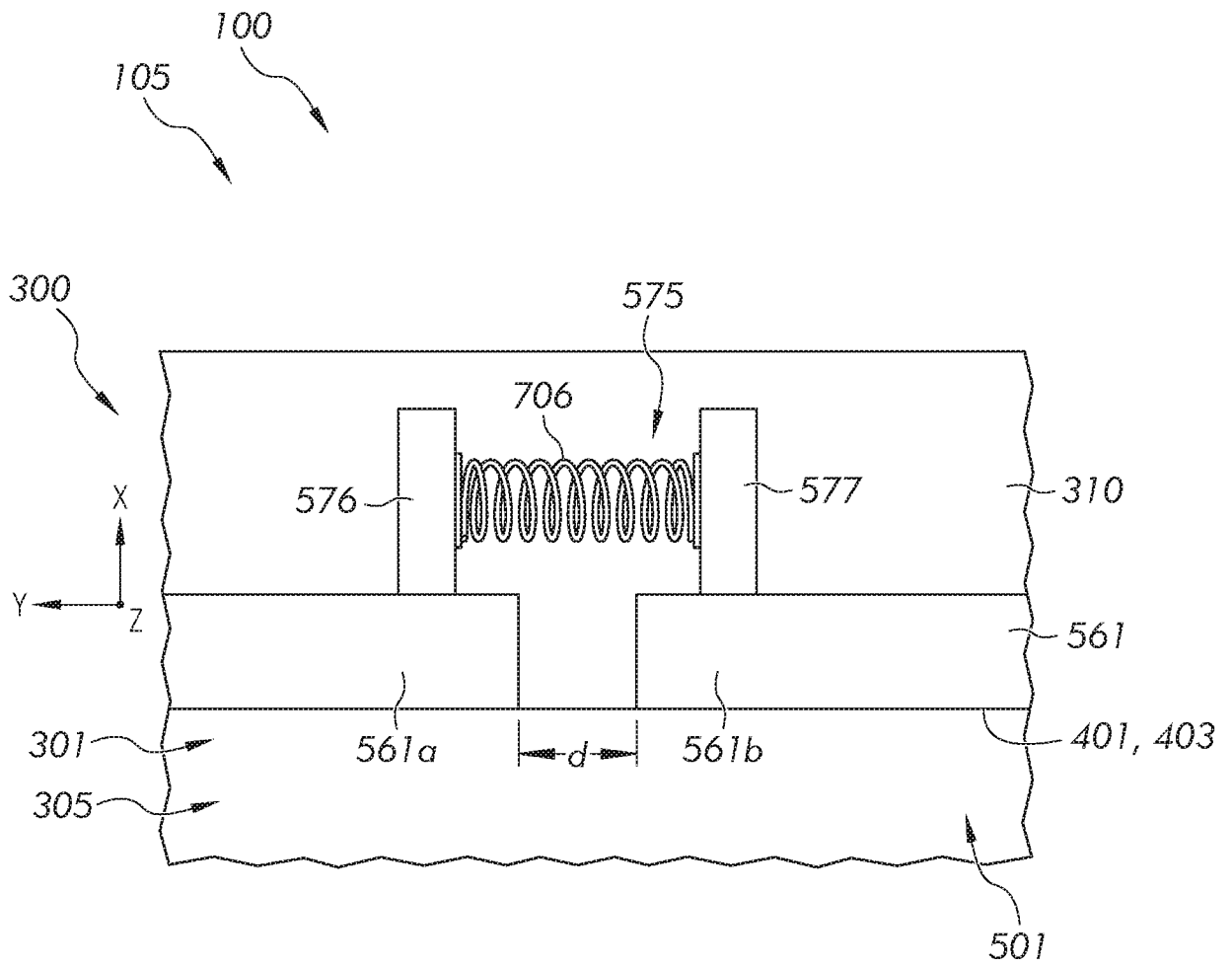


FIG. 17

INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2019/023090

A. CLASSIFICATION OF SUBJECT MATTER  
INV. C03B5/027 F27D11/04  
ADD.  
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED  
Minimum documentation searched (classification system followed by classification symbols)  
C03B H05B F27B F27D  
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 151 918 A (ARGENT RONALD D [US] ET AL) 29 September 1992 (1992-09-29) claims 1, 6 and 11, figures 5b, 5e, column 2, lines 1-10, column 5, lines 22-32, column 7, lines 22-26 and 36-41 -----	1-20
X	US 5 199 043 A (MEREDITH DANE [US]) 30 March 1993 (1993-03-30) figure 1 and claims -----	1,19
X	US 4 290 475 A (BERG CHARLES A) 22 September 1981 (1981-09-22) figures -----	1,19
Y		7-16,18,20
Y	WO 2017/079390 A1 (CORNING INC [US]) 11 May 2017 (2017-05-11) figures and paragraph [0040] -----	7-16,18,20

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	"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
"E" earlier application or patent but published on or after the international filing date	"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
"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)	"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
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search <b>14 June 2019</b>	Date of mailing of the international search report <b>24/06/2019</b>
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer <b>Gkerou, Elisavet</b>
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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No PCT/US2019/023090
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