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(54) **ROLL-TO-ROLL ELECTROLESS PLATING SYSTEM WITH LIQUID FLOW BEARING**

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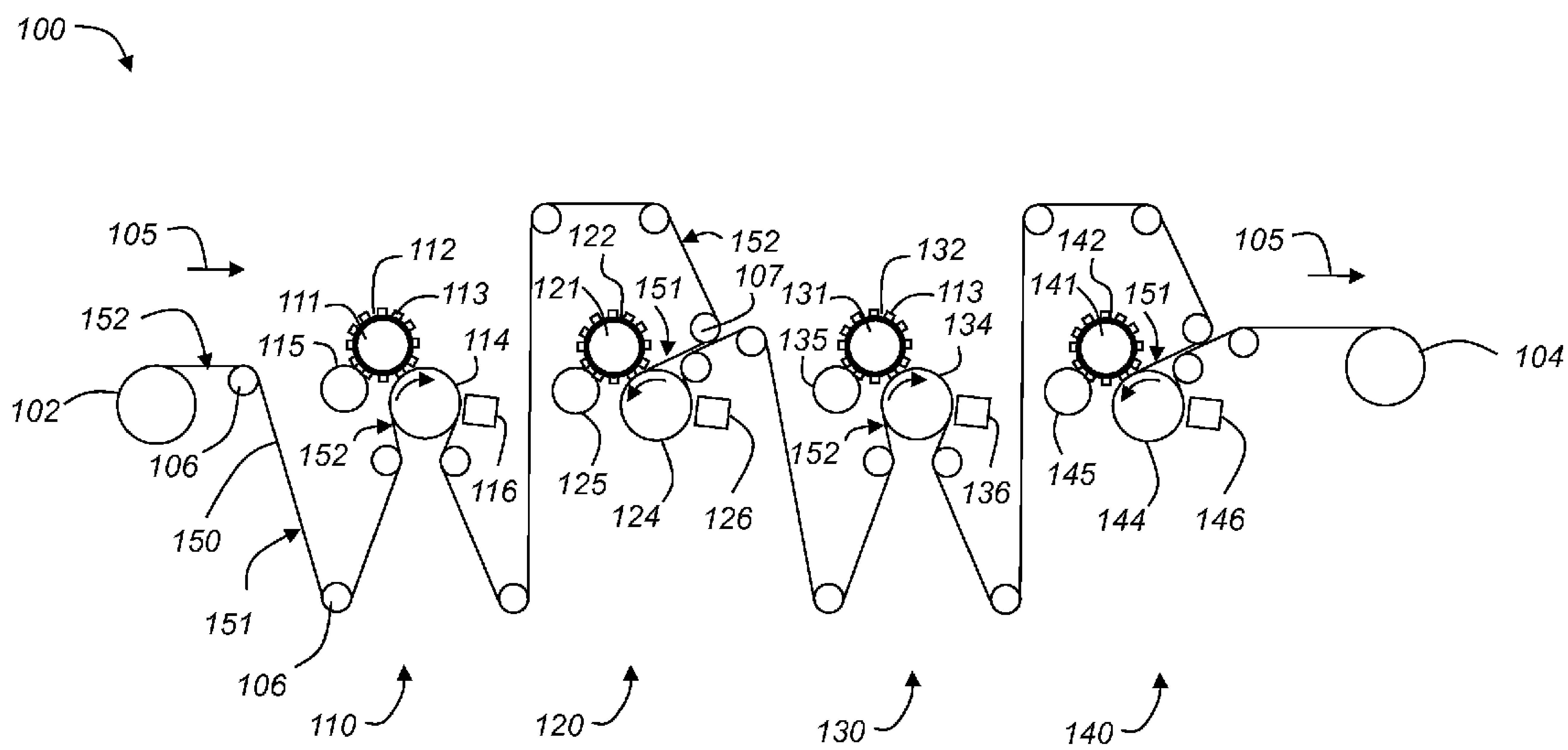
(57) **ABSTRACT**

A roll-to-roll electroless plating system includes a web advance system for advancing a web of media through a tank containing plating solution where a plating substance in the plating solution is plated onto predetermined locations on the web of media. The web advance system includes a web-guiding roller that is at least partially submerged within the plating solution in the tank. A roller mount is provided for supporting the web-guiding roller while allowing free rotation of the web-guiding roller. A pump is configured to cause plating solution to flow between a bearing surface on the web-guiding roller and a bearing surface on the roller mount.



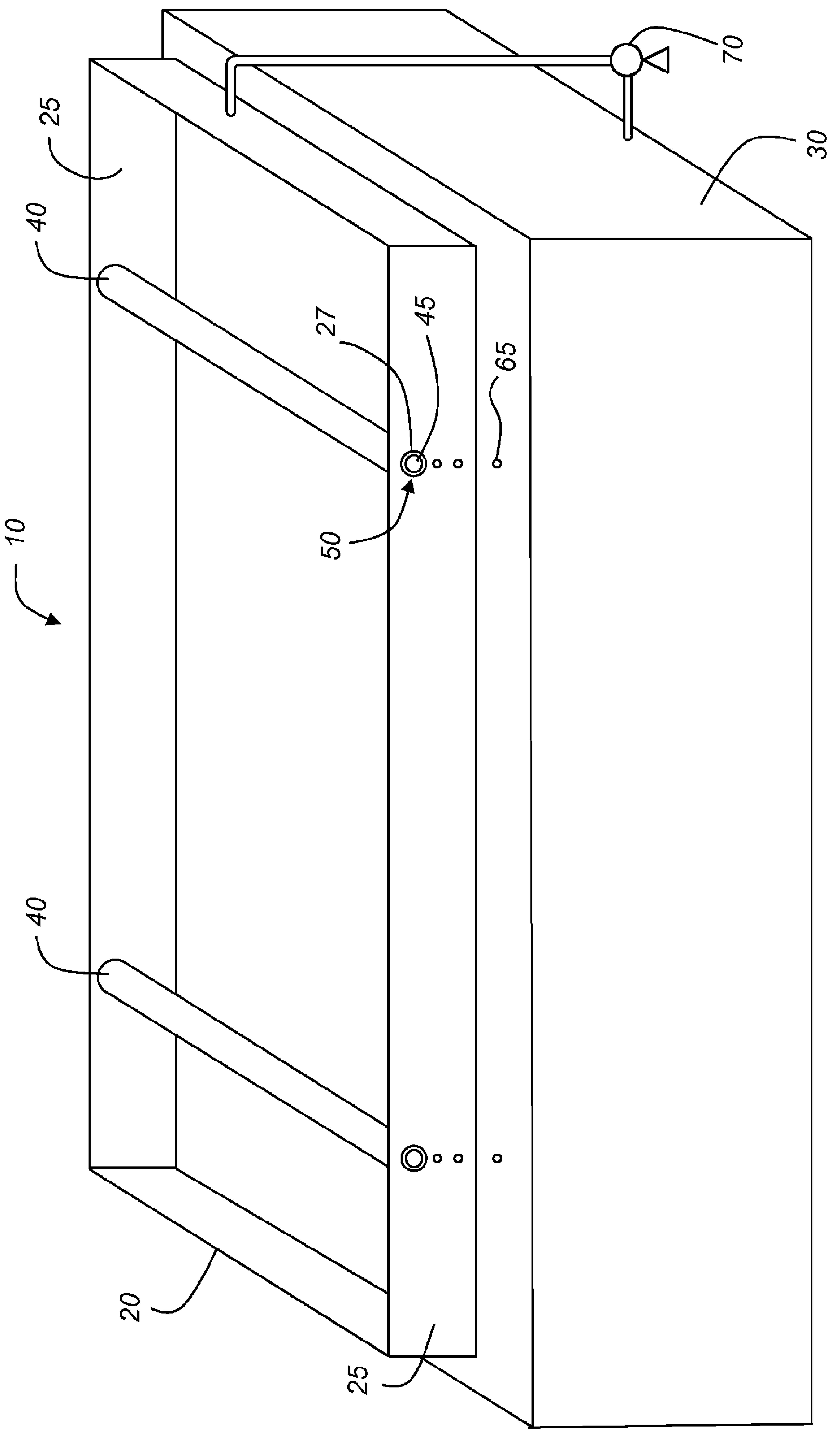
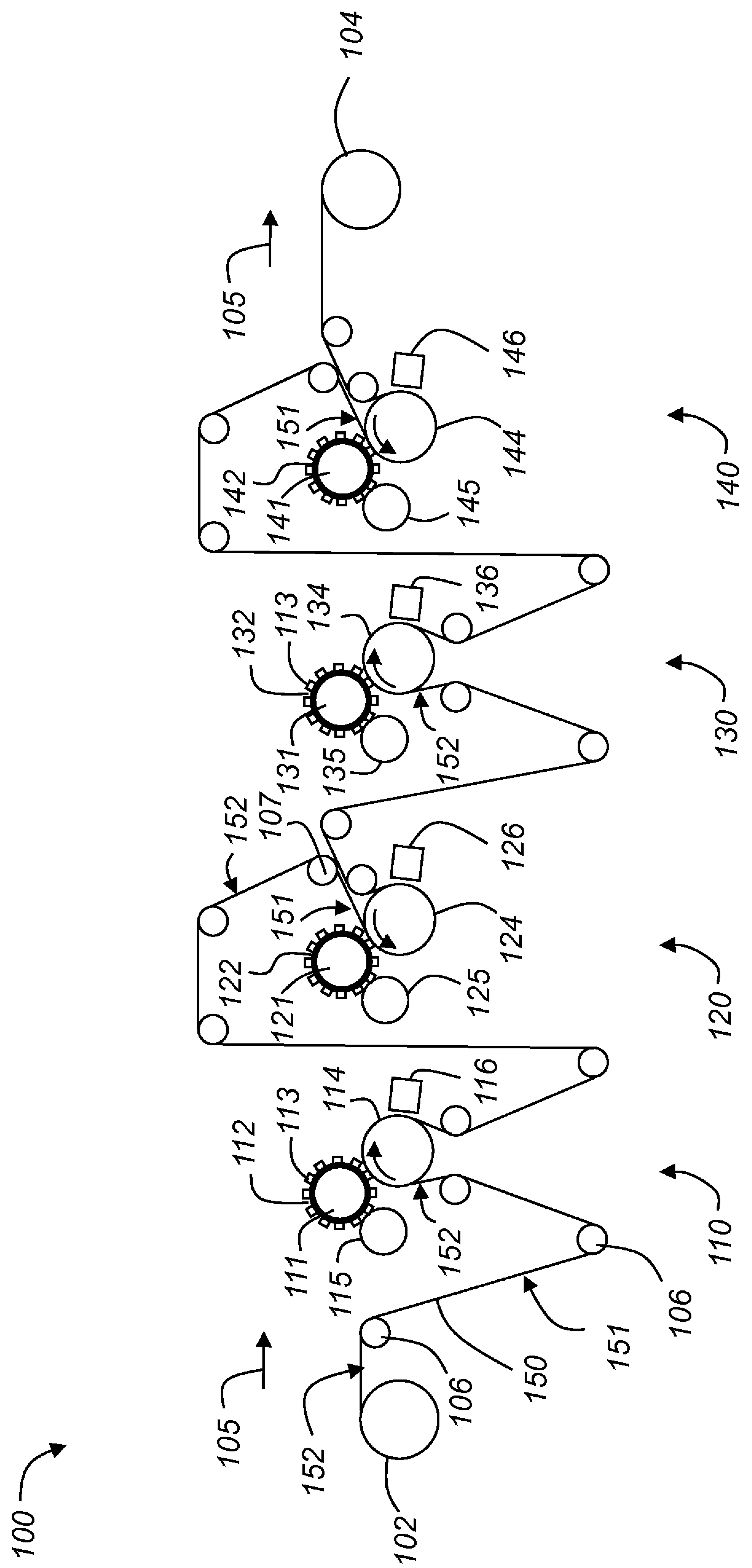


FIG. 1 (Prior Art)


100
102
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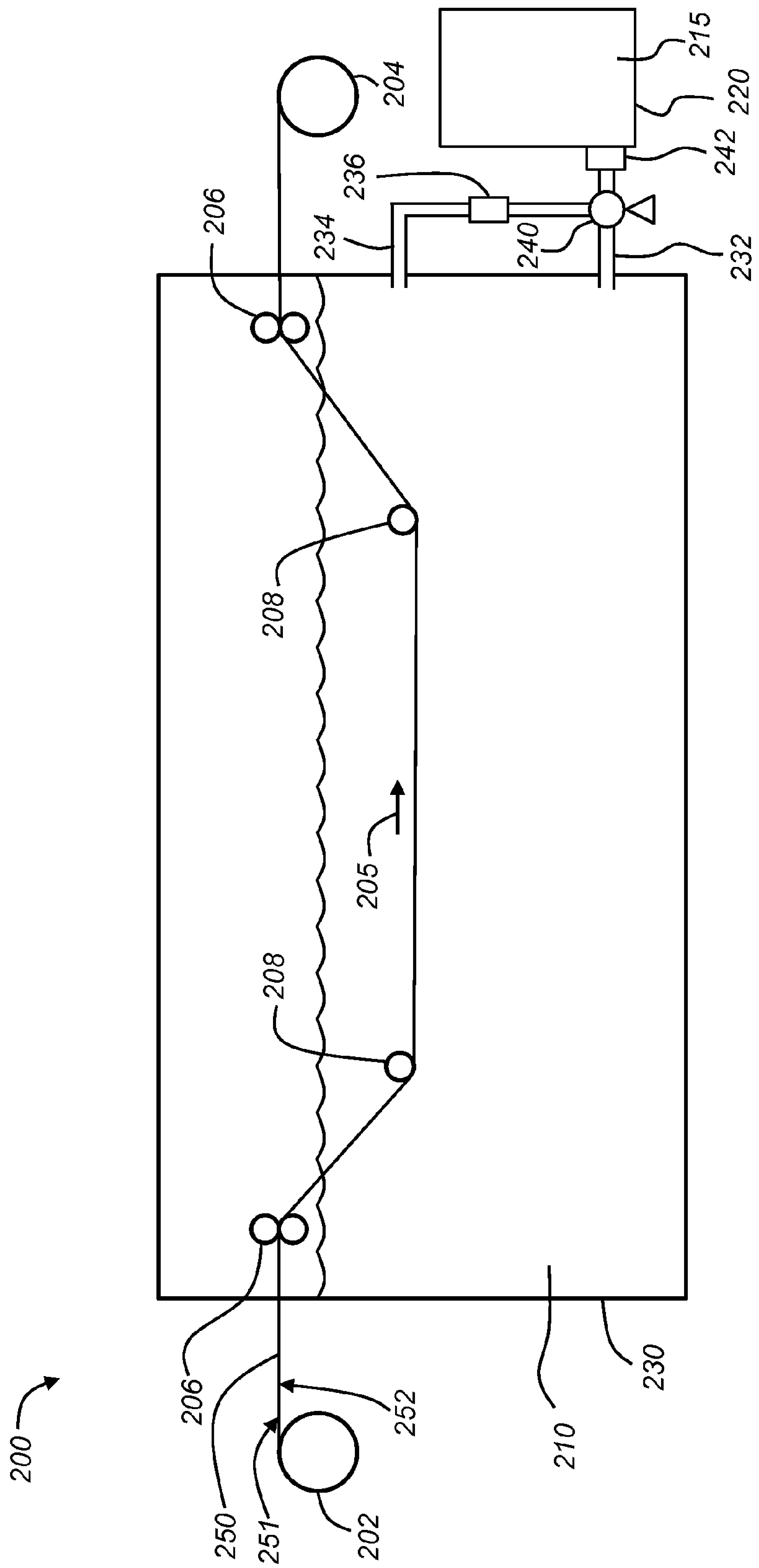
151
152

FIG. 2



200
202
204
205
206
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208
208
210
215
220
230
232
234
236
240
242
250
251
252

FIG. 3

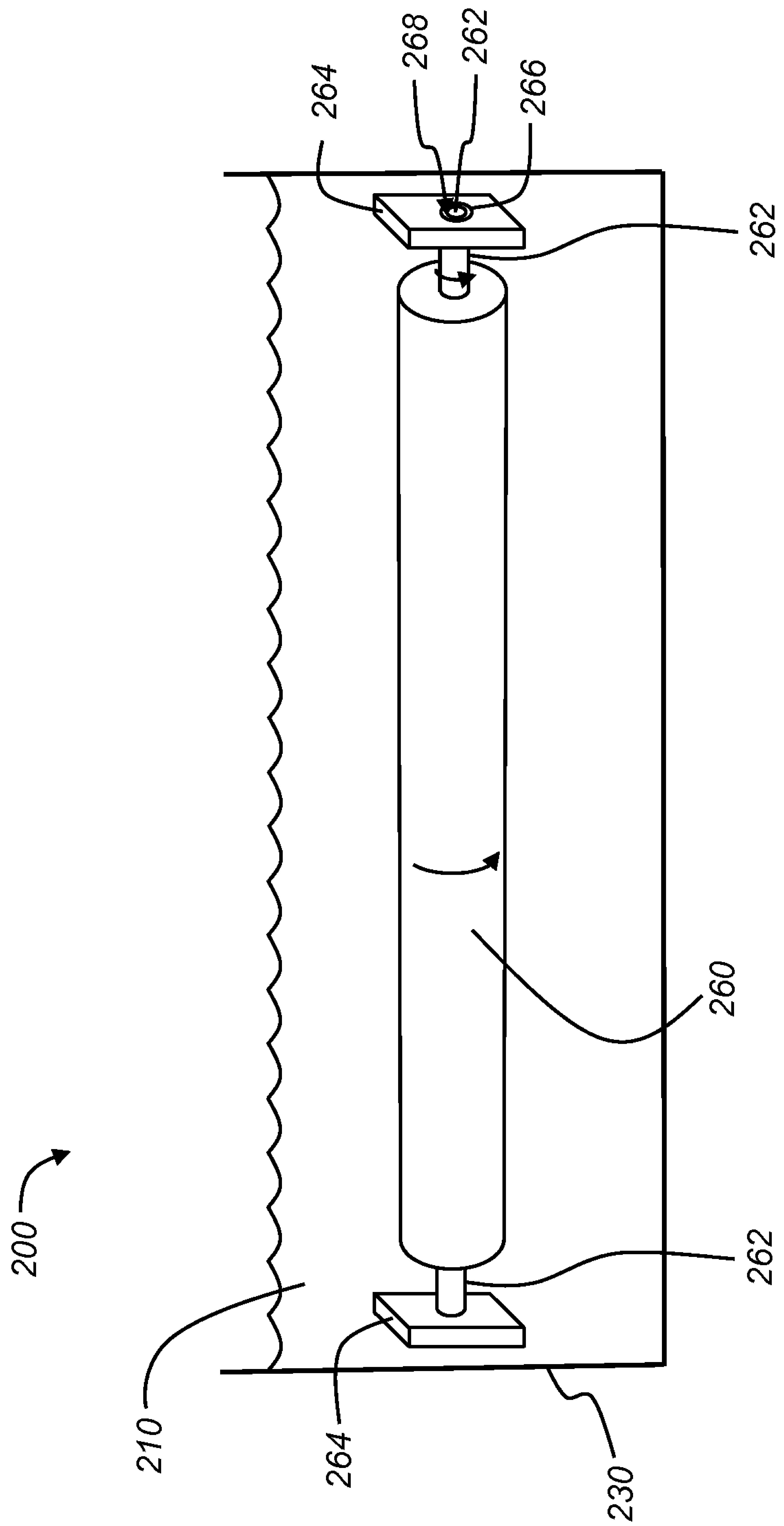

FIG. 4

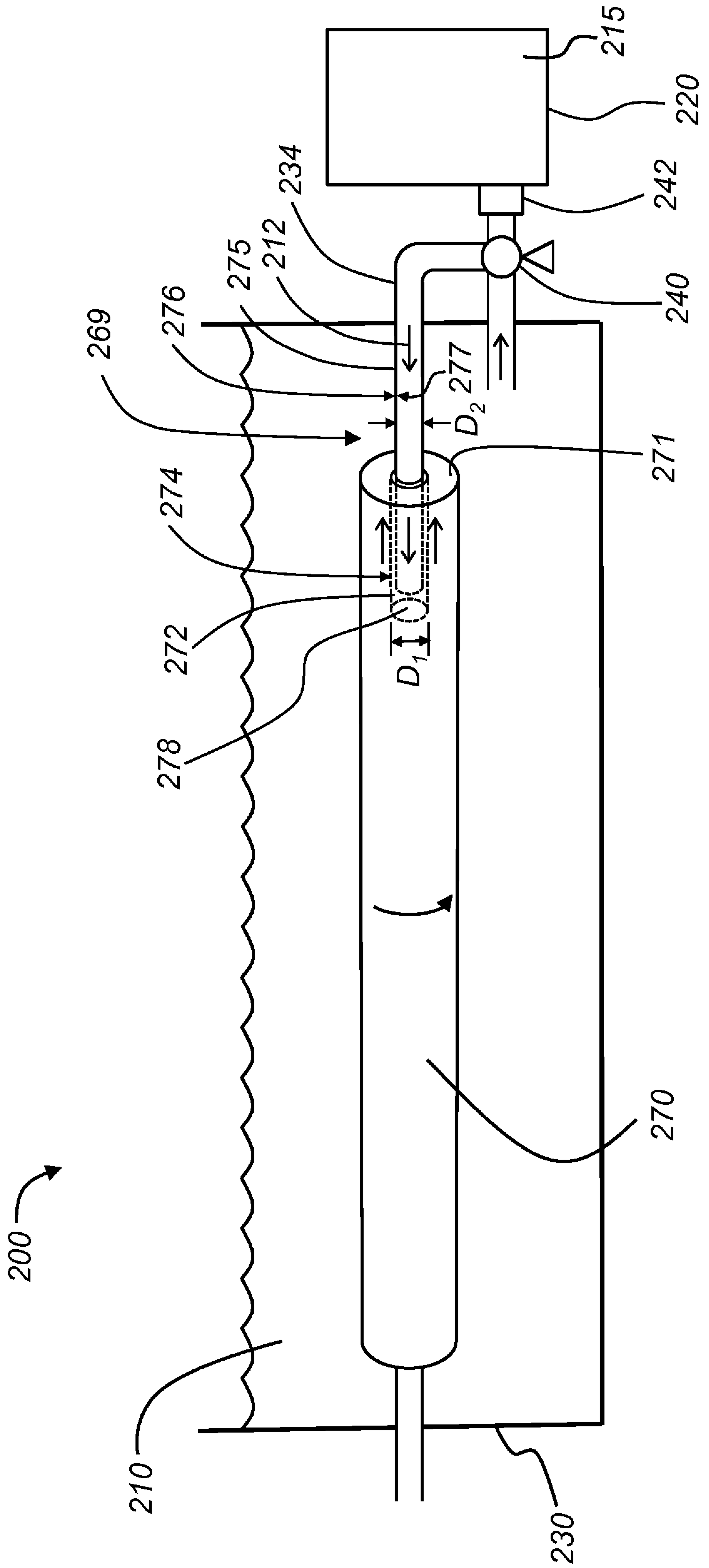
215
220
234
242
212
275
240
276
269
277
D_2
271
274
272
D_1
278
270
200
210
230

FIG. 5

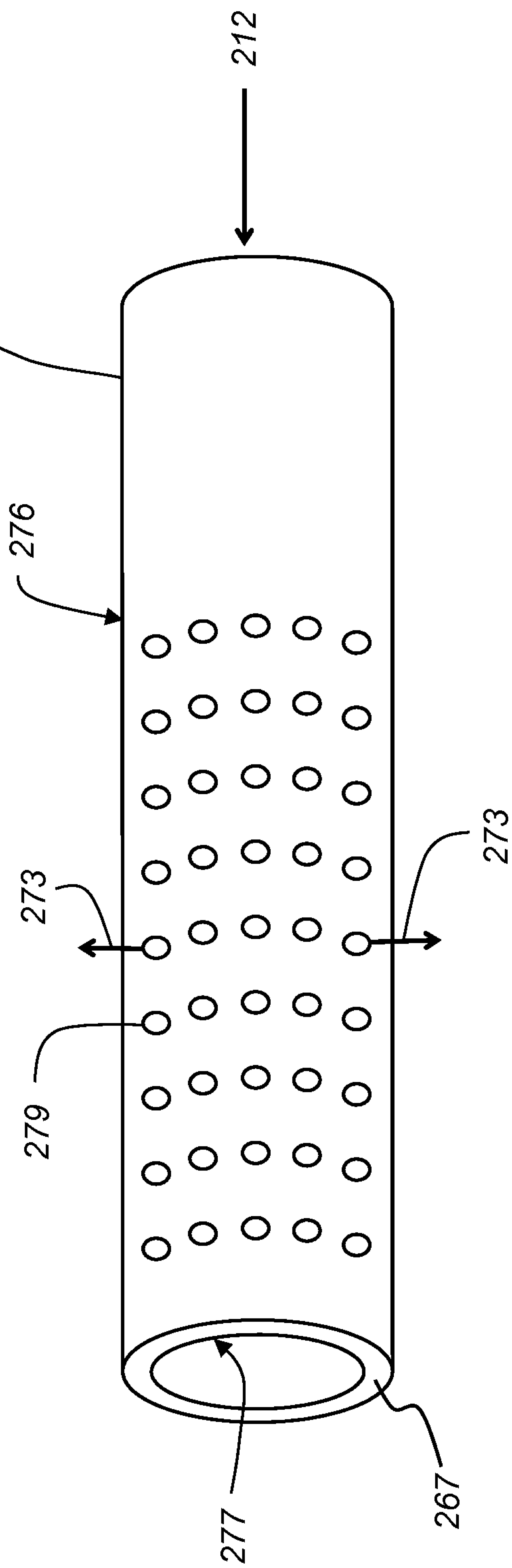

FIG. 6

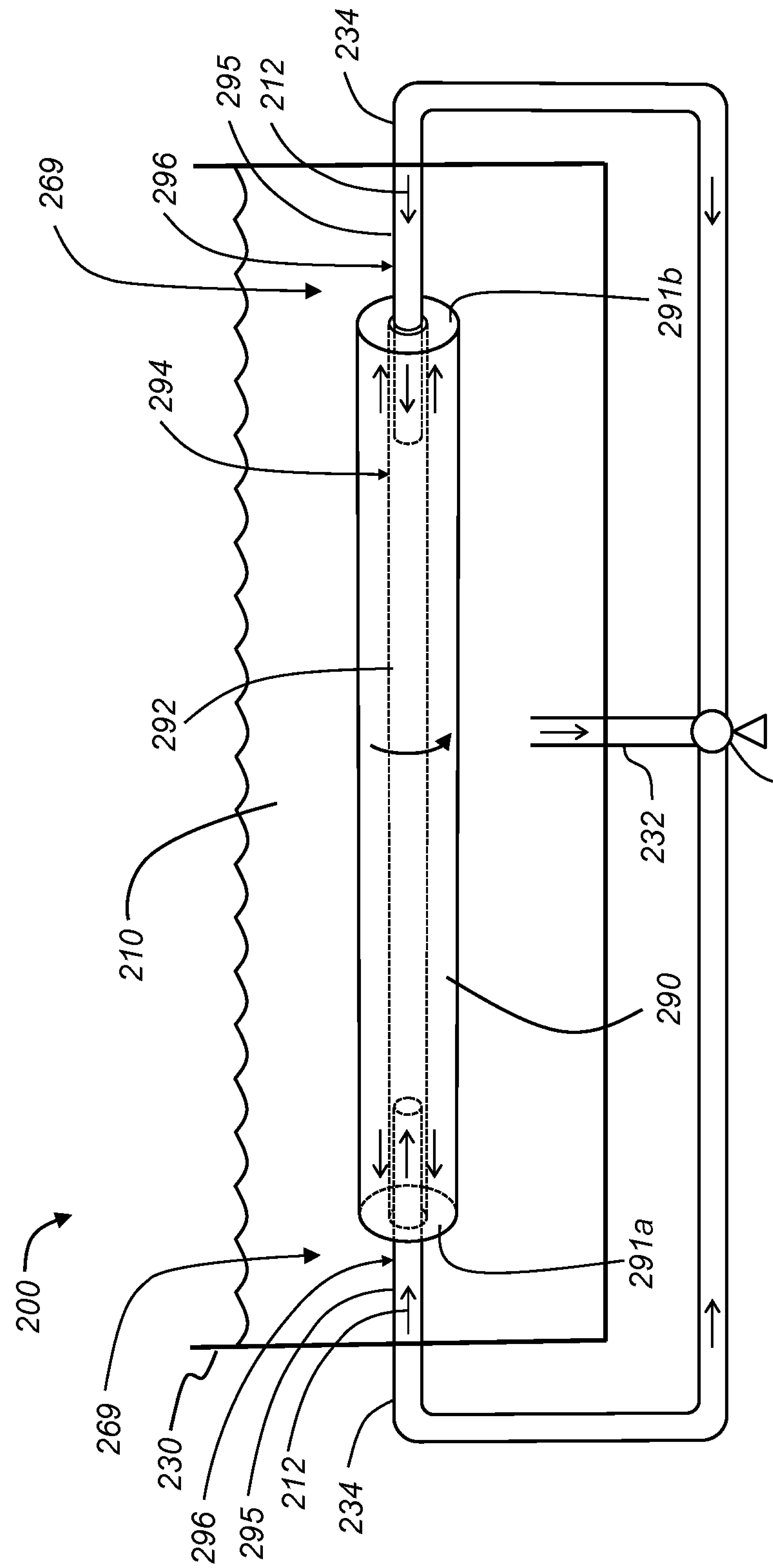
200
269
296
295
212
234
291b
294
292
210
290
232
240
291a
269
230
296
295
212
234

FIG. 7

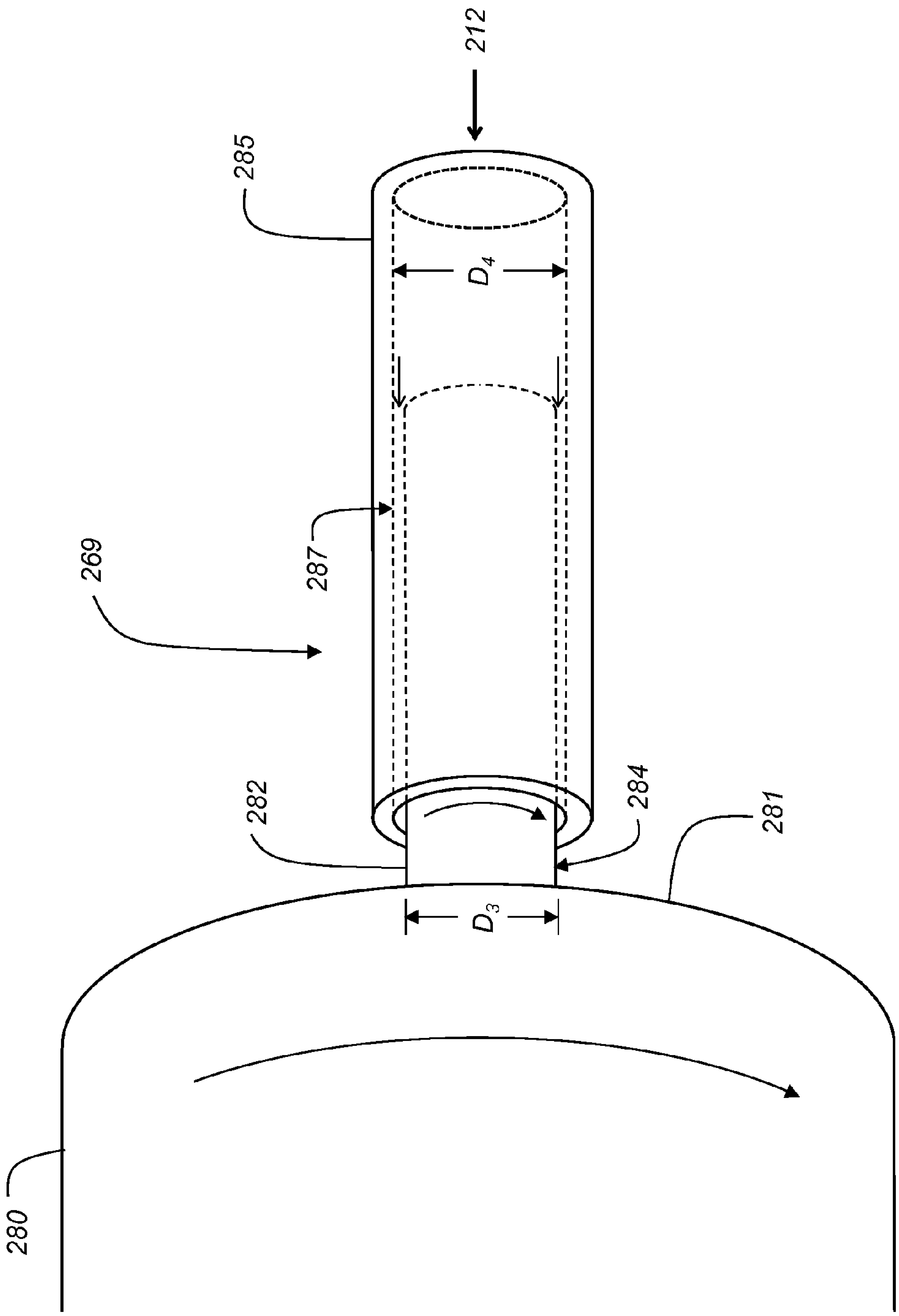

FIG. 8

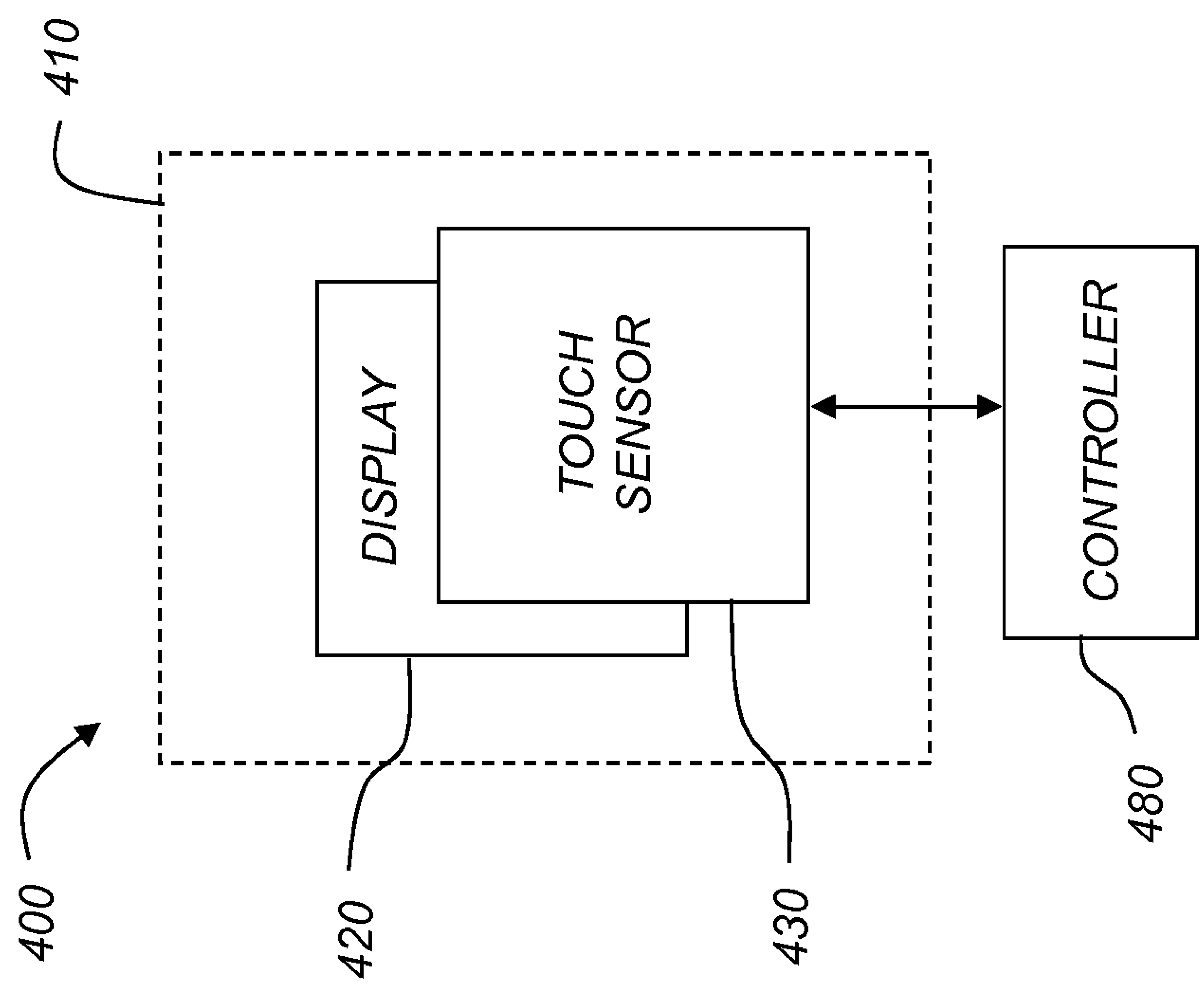

FIG. 9

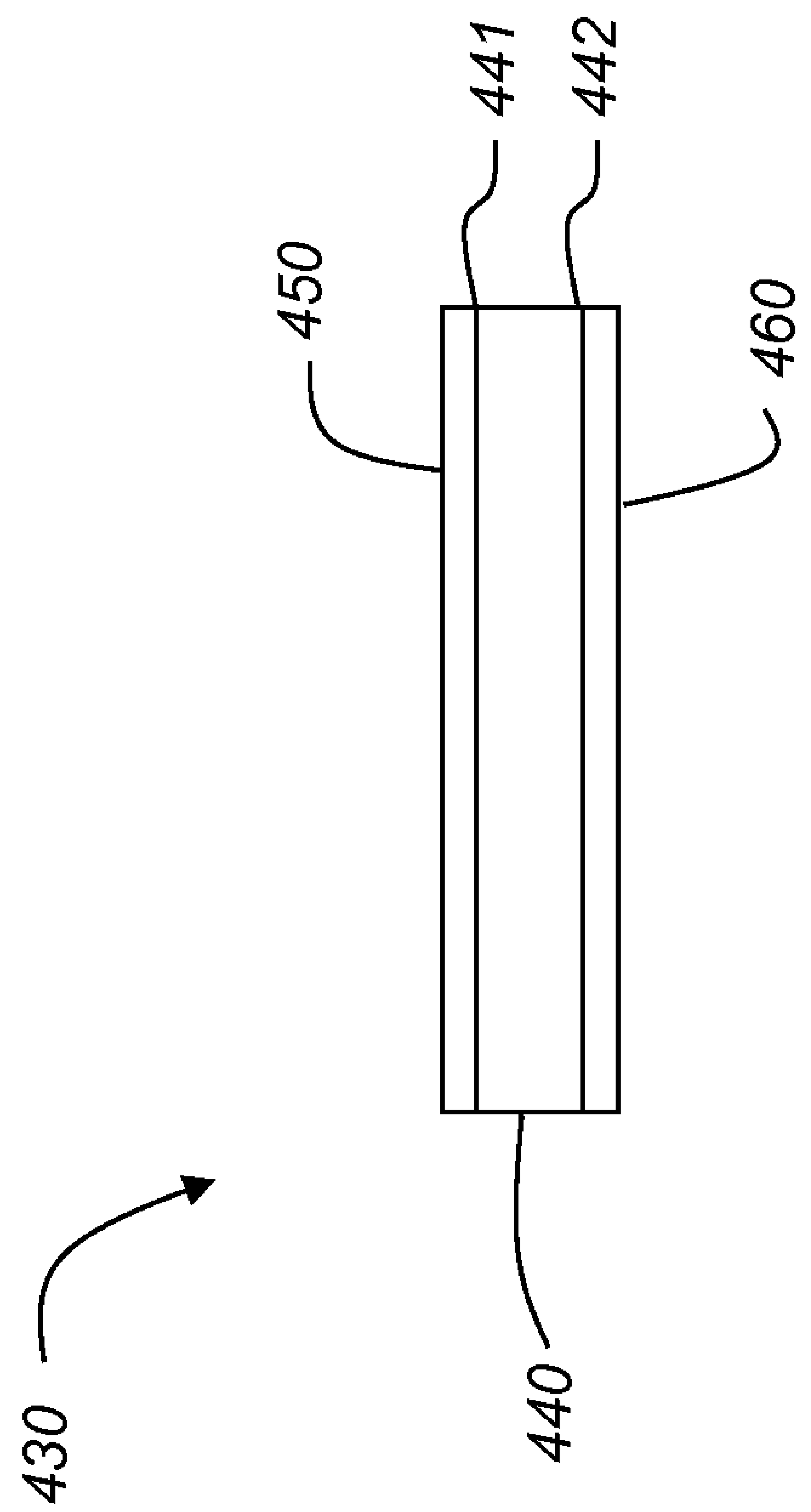

FIG. 10

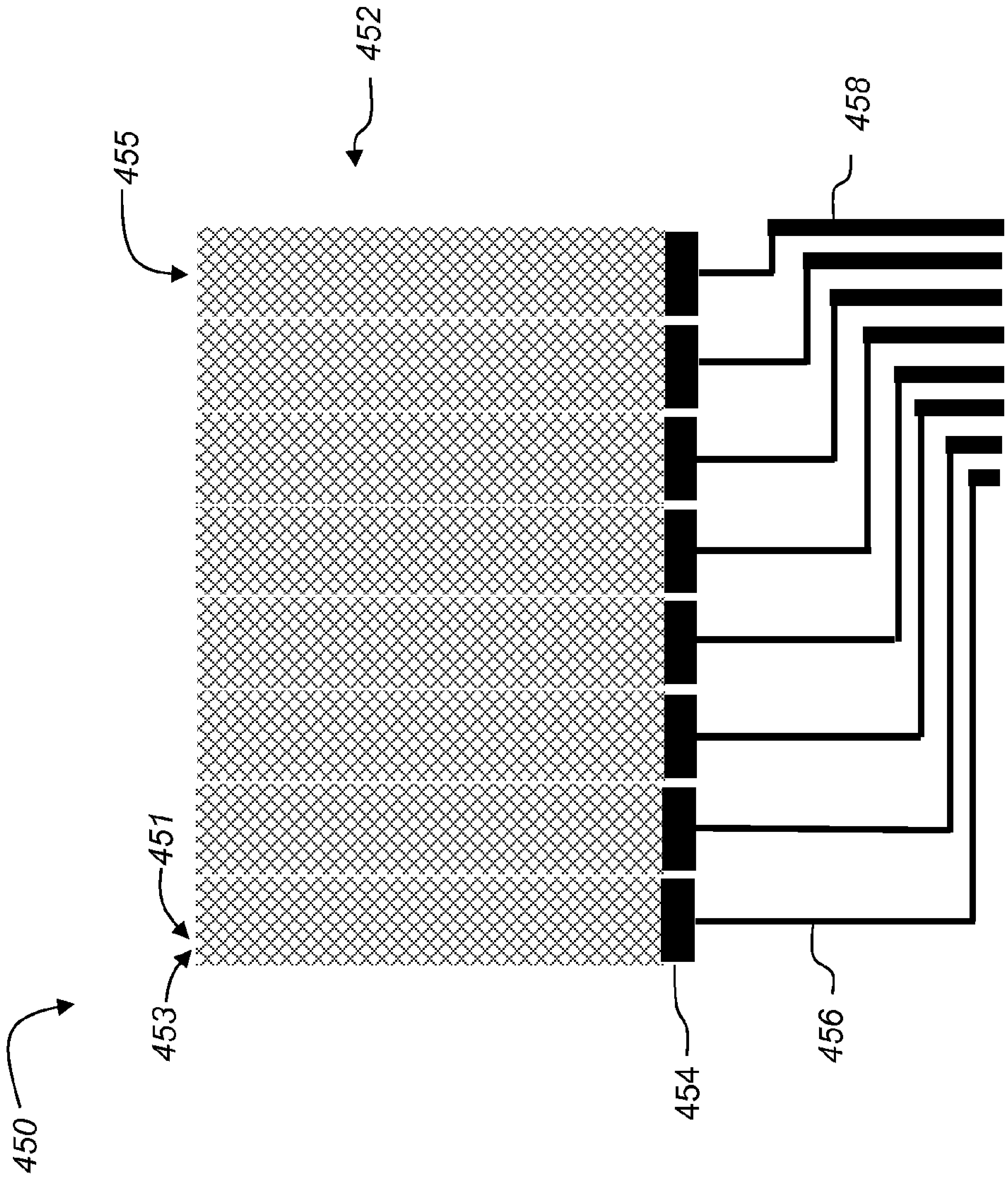

FIG. 11

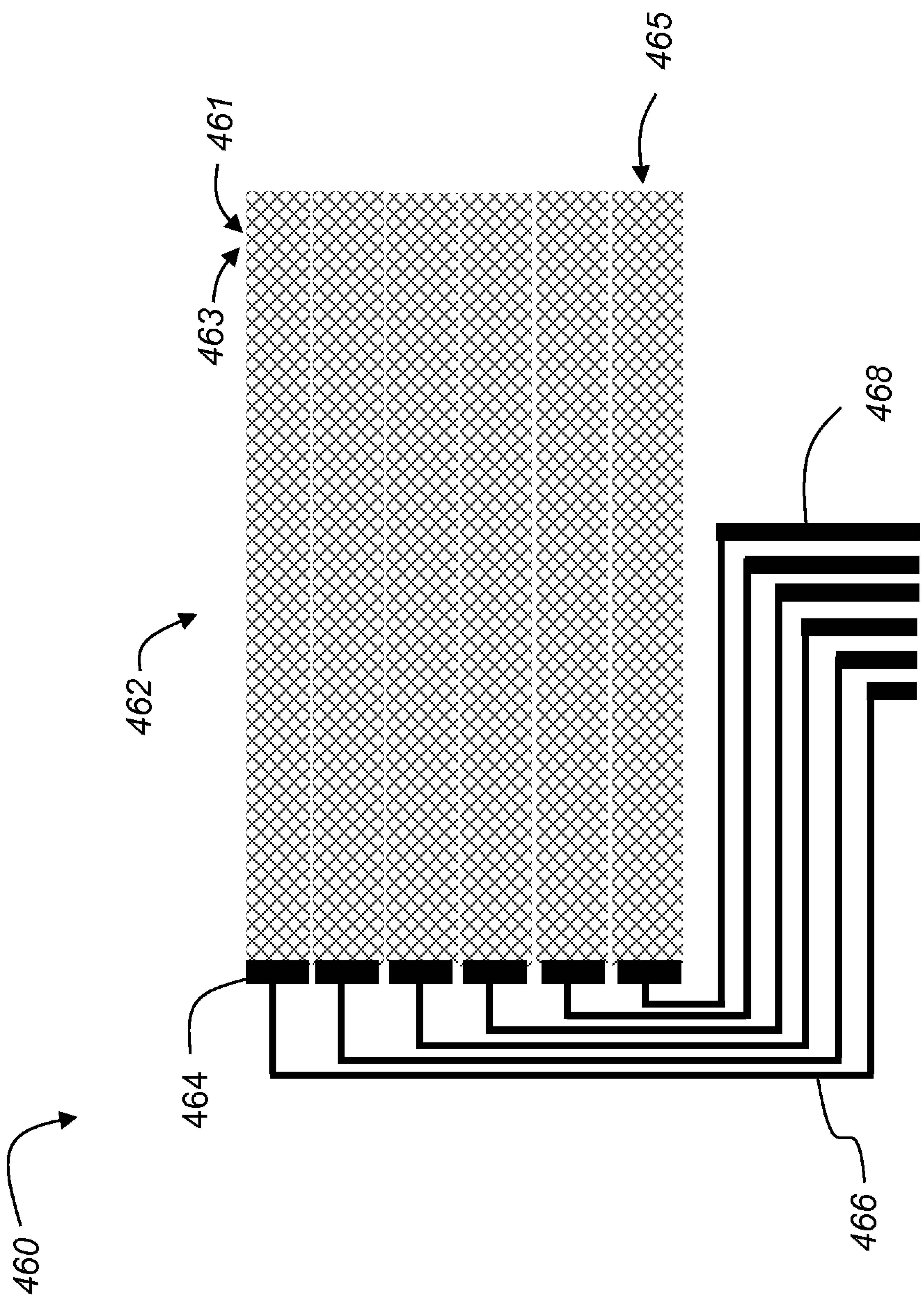

FIG. 12

ROLL-TO-ROLL ELECTROLESS PLATING SYSTEM WITH LIQUID FLOW BEARING

FIELD OF THE INVENTION

[0001] This invention pertains to the field of roll-to-roll electroless plating, and more particularly to a bearing for a web-guiding roller within a plating solution.

BACKGROUND OF THE INVENTION

[0002] Electroless plating, also known as chemical or auto-catalytic plating, is a non-galvanic plating process that involves chemical reactions in an aqueous plating solution that occur without the use of external electrical power. Typically, the plating occurs as hydrogen is released by a reducing agent and oxidized, thus producing a negative charge on the surface of the part to be plated. The negative charge attracts metal ions out of the plating solution to adhere as a metalized layer on the surface. Using electroless plating to provide metallization in predetermined locations can be facilitated by first depositing a catalytic material in the predetermined locations. This can be done, for example by printing features using an ink containing a catalytic component.

[0003] Touch screens are visual displays with areas that may be configured to detect both the presence and location of a touch by, for example, a finger, a hand or a stylus. Touch screens can be found in televisions, computers, computer peripherals, mobile computing devices, automobiles, appliances and game consoles, as well as in other industrial, commercial and household applications. A capacitive touch screen includes a substantially transparent substrate which is provided with electrically conductive patterns that do not excessively impair the transparency—either because the conductors are made of a material, such as indium tin oxide, that is substantially transparent, or because the conductors are sufficiently narrow that the transparency is provided by the comparatively large open areas not containing conductors. For capacitive touch screens having metallic conductors, it is advantageous for the features to be highly conductive but also very narrow. Capacitive touch screen sensor films are an example of an article having very fine features with improved electrical conductivity resulting from an electroless plated metal layer.

[0004] Projected capacitive touch screen technology is a variant of capacitive touch screen technology. Projected capacitive touch screens are made up of a matrix of rows and columns of conductive material that form a grid. Voltage applied to this grid creates a uniform electrostatic field, which can be measured. When a conductive object, such as a finger, comes into contact, it distorts the local electrostatic field at that point. This is measurable as a change in capacitance. The capacitance can be measured at every intersection point on the grid. In this way, the system is able to accurately track touches. Projected capacitive touch screens can use either mutual capacitive sensors or self capacitive sensors. In mutual capacitive sensors, there is a capacitor at every intersection of each row and each column. A 16×14 array, for example, would have 224 independent capacitors. A voltage is applied to the rows or columns. Bringing a finger or conductive stylus close to the surface of the sensor changes the local electrostatic field which reduces the mutual capacitance. The capacitance change at every individual point on the grid can be measured to accurately determine the touch location by measuring the voltage in the other axis. Mutual capacitance allows multi-touch operation where multiple fingers, palms or styli can be accurately tracked at the same time.

[0005] International patent application WO2013/063188 by Petcavich et al., entitled "Method of manufacturing a capacitive touch sensor circuit using a roll-to-roll process to print a conductive microscopic patterns on a flexible dielectric substrate," discloses a method of manufacturing a capacitive touch sensor using a roll-to-roll process to print a conductor pattern on a flexible transparent dielectric substrate. A first conductor pattern is printed on a first side of the dielectric substrate using a first flexographic printing plate and is then cured. A second conductor pattern is printed on a second side of the dielectric substrate using a second flexographic printing plate and is then cured. The ink used to print the patterns includes a catalyst that acts as seed layer during a subsequent electroless plating operation. The electrolessly plated material (e.g., copper) provides the low resistivity in the narrow lines of the grid needed for excellent performance of the capacitive touch sensor. Petcavich et al. indicate that the line width of the flexographically printed material can be 1 to 50 microns.

[0006] Flexography is a method of printing or pattern formation that is commonly used for high-volume printing runs. It is typically employed in a roll-to-roll format for printing on a variety of soft or easily deformed materials including, but not limited to, paper, paperboard stock, corrugated board, polymeric films, fabrics, metal foils, glass, glass-coated materials, flexible glass materials and laminates of multiple materials. Coarse surfaces and stretchable polymeric films are also economically printed using flexography.

[0007] Flexographic printing members are sometimes known as relief printing members, relief-containing printing plates, printing sleeves, or printing cylinders, and are provided with raised relief images onto which ink is applied for application to a printable material. While the raised relief images are inked, the recessed relief "floor" should remain free of ink.

[0008] Although flexographic printing has conventionally been used in the past for printing of images, more recent uses of flexographic printing have included functional printing of devices, such as touch screen sensor films, antennas, and other devices to be used in electronics or other industries. Such devices typically include electrically conductive patterns.

[0009] To improve the optical quality and reliability of the touch screen, it has been found to be preferable that the width of the grid lines be approximately 2 to 10 microns, and even more preferably to be 4 to 8 microns. In addition, in order to be compatible with the high-volume roll-to-roll manufacturing process, it is preferable for the roll of flexographically printed material to be electroless plated in a roll-to-roll electroless plating system. More conventionally, electroless plating is performed by immersing the item to be plated in a tank of plating solution. However, for high volume uniform plating of features on both sides of the web of substrate material, it is preferable to perform the electroless plating in a roll-to-roll electroless plating system.

[0010] Roll-to-roll electroless plating systems are commercially available from Chemcut Corporation, for example. With reference to prior art FIG. **1**, in such a roll-to-roll electroless plating system **10**, a web of media is advanced substantially horizontally through a pan **20** containing plating solution. The plating solution in the pan is replenished from a sump **30** using pump **70**. Web-guiding rollers **40** guide the web of media (not shown) through the pan of plating solution. Both ends of a conventional web-guiding roller **40** include a shaft **45** about which it rotates. Typically each shaft **45** of the web-guiding roller **40** extends through a hole **27** in a side wall **25** of the pan. The outer surface of the rotating shaft **45** and the inner surface of the hole **27** form a bearing **50**. Plating solution is allowed to trickle between the bearing surfaces of the outer surface of the rotating shaft **45** and the inner surface of the hole **27**. Drops **65** of plating solution drip back into the sump **30**. It has been found that the flow of plating solution past the bearing surfaces is effective in keeping metal in the plating solution from plating out on the bearing surfaces, which would otherwise cause the bearing **50** to increase its friction or even freeze up over time.

[0011] An alternate configuration of a roll-to-roll electroless plating system is to have a tank of plating solution without a separate sump and pan. In this configuration, some of the web-guiding rollers can be at least partially submerged within the plating solution within the tank. Because there is no sump to catch drops of plating solution as in the roll-to-roll electroless plating system **10** of FIG. **1**, having the shaft of a web-guiding roller rotating within a hole in a side wall of the tank would waste plating solution due to leakage. If the rotating shaft and its bearing are simply submerged in plating solution, there would be no driving force for causing a flow of plating solution past the bearing surfaces. Such a bearing would be susceptible to increased friction or freezing up due to the tendency of metal to electrolessly plate onto the bearing surfaces.

[0012] There remains a need for a bearing configuration for a web-guiding roller submerged in a tank of electroless plating solution such that plating out onto the bearing surfaces is inhibited.

SUMMARY OF THE INVENTION

[0013] The present invention represents a roll-to-roll electroless plating system, comprising:

[0014] a tank containing a plating solution;

[0015] a web advance system for advancing a web of media in an in-track direction along a web transport path from an input roll through the plating solution in the tank to a take-up roll, wherein a plating substance in the plating solution is plated onto predetermined locations on a surface of the web of media as it is advanced through the plating solution in the tank, and wherein the web advance system includes:

- **[0016]** a web-guiding roller for guiding the web of media, the web-guiding roller being at least partially submerged within the plating solution in the tank; and
- **[0017]** a roller mount for supporting the web-guiding roller while allowing free rotation of the web-guiding roller, wherein the web-guiding roller and the roller mount include corresponding bearing surfaces; and

[0018] a pump configured to cause plating solution to flow between the bearing surface of the web-guiding roller and the bearing surface of the roller mount.

[0019] This invention has the advantage that pumping plating solution between the bearing surfaces reduces the amount of the plating material that plates out on the bearing surfaces.

[0020] It has the additional advantage that the web-guiding roller can be fully submerged within the plating solution without suffering from problems caused by the plating material that plates out on the bearing surfaces.

[0021] It has the further advantage that using the plating liquid as the lubricant for the bearing surfaces prevents the plating liquid from being contaminated as could occur if a different lubricant were used.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIG. **1** is a perspective of a prior art roll-to-roll electroless plating system including a pan and a sump;

[0023] FIG. **2** is a schematic side view of a flexographic printing system for roll-to-roll printing on both sides of a substrate;

[0024] FIG. **3** is a schematic side view of a roll-to-roll electroless plating system for use with embodiments of the invention;

[0025] FIG. **4** is a perspective of a roller mount for a submerged roller that is susceptible to electroless plating on the bearing surfaces;

[0026] FIG. **5** is a schematic side view of a roll-to-roll electroless plating system according to an embodiment of the invention;

[0027] FIG. **6** is a close-up perspective of a hollow shaft roller mount according to another embodiment of the invention;

[0028] FIG. **7** is a schematic side view of a roll-to-roll electroless plating system according to another embodiment of the invention;

[0029] FIG. **8** is a close-up perspective of a roller mount and web-guiding roller according to another embodiment of the invention;

[0030] FIG. **9** is a high-level system diagram for an apparatus having a touch screen with a touch sensor that can be printed using embodiments of the invention;

[0031] FIG. **10** is a side view of the touch sensor of FIG. **9**;

[0032] FIG. **11** is a top view of a conductive pattern printed on a first side of the touch sensor of FIG. **10**; and

[0033] FIG. **12** is a top view of a conductive pattern printed on a second side of the touch sensor of FIG. **10**.

[0034] It is to be understood that the attached drawings are for purposes of illustrating the concepts of the invention and may not be to scale.

DETAILED DESCRIPTION OF THE INVENTION

[0035] The present description will be directed in particular to elements forming part of, or cooperating more directly with, an apparatus in accordance with the present invention. It is to be understood that elements not specifically shown, labeled, or described can take various forms well known to those skilled in the art. In the following description and drawings, identical reference numerals have been used, where possible, to designate identical elements. It is to be understood that elements and components can be referred to in singular or plural form, as appropriate, without limiting the scope of the invention.

[0036] The invention is inclusive of combinations of the embodiments described herein. References to “a particular embodiment” and the like refer to features that are present in at least one embodiment of the invention. Separate references to “an embodiment” or “particular embodiments” or the like do not necessarily refer to the same embodiment or embodiments; however, such embodiments are not mutually exclusive, unless so indicated or as are readily apparent to one of skill in the art. It should be noted that, unless otherwise explicitly noted or required by context, the word "or" is used in this disclosure in a non-exclusive sense.

[0037] The example embodiments of the present invention are illustrated schematically and not to scale for the sake of clarity. One of ordinary skill in the art will be able to readily determine the specific size and interconnections of the elements of the example embodiments of the present invention.

[0038] References to upstream and downstream herein refer to direction of flow. Web media moves along a media path in a web advance direction from upstream to downstream. Similarly, fluids flow through a fluid line in a direction from upstream to downstream.

[0039] As described herein, the example embodiments of the present invention provide a roll-to-roll electroless plating system having a web-guiding roller with a bearing at least partially submerged in a plating solution, such that plating solution is forced past the bearing surfaces. In an exemplary configuration, the roll-to-roll electroless plating system is useful for metalizing printed features in sensor films incorporated into touch screens. However, many other applications are emerging for printing and electroless plating of functional devices that can be incorporated into other electronic, communications, industrial, household, packaging and product identification systems (such as RFID) in addition to touch screens. In addition, roll-to-roll electroless plating systems can be used to plate items for decorative purposes rather than electronic purposes and such applications are contemplated as well.

[0040] FIG. **2** is a schematic side view of a flexographic printing system **100** that can be used in embodiments of the invention for roll-to-roll printing of a catalytic ink on both sides of a substrate **150** for subsequent electroless plating. Substrate **150** is fed as a web from supply roll **102** to take-up roll **104** through flexographic printing system **100**. Substrate **150** has a first side **151** and a second side **152**.

[0041] The flexographic printing system **100** includes two print modules **120** and **140** that are configured to print on the first side **151** of substrate **150**, as well as two print modules **110** and **130** that are configured to print on the second side **152** of substrate **150**. The web of substrate **150** travels overall in roll-to-roll direction **105** (left to right in the example of FIG. **2**). However, various rollers **106** and **107** are used to locally change the direction of the web of substrate as needed for adjusting web tension, providing a buffer, and reversing the substrate **150** for printing on an opposite side. In particular, note that in print module **120** roller **107** serves to reverse the local direction of the web of substrate **150** so that it is moving substantially in a right-to-left direction.

[0042] Each of the print modules **110**, **120**, **130**, **140** includes some similar components including a respective plate cylinder **111**, **121**, **131**, **141**, on which is mounted a respective flexographic printing plate **112**, **122**, **132**, **142**, respectively. Each flexographic printing plate **112**, **122**, **132**, **142** has raised features **113** defining an image pattern to be printed on the substrate **150**. Each print module **110**, **120**, **130**, **140** also includes a respective impression cylinder **114**, **124**, **134**, **144** that is configured to force a side of the substrate **150** into contact with the corresponding flexographic printing plate **112**, **122**, **132**, **142**. Impression cylinders **124** and **144** of print modules **120** and **140** (for printing on first side **151** of substrate **150**) rotate counter-clockwise in the view shown in FIG. **2**, while impression cylinders **114** and **134** of print modules **110** and **130** (for printing on second side **152** of substrate **150**) rotate clockwise in this view.

[0043] Each print module **110**, **120**, **130**, **140** also includes a respective anilox roller **115**, **125**, **135**, **145** for providing ink to the corresponding flexographic printing plate **112**, **122**, **132**, **142**. As is well known in the printing industry, an anilox roller is a hard cylinder, usually constructed of a steel or aluminum core, having an outer surface containing millions of very fine dimples, known as cells. Ink is provided to the anilox roller by a tray or chambered reservoir (not shown). In some embodiments, some or all of the print modules **110**, **120**, **130**, **140** also include respective UV curing stations **116**, **126**, **136**, **146** for curing the printed ink on substrate **150**.

[0044] FIG. **3** is a schematic side view of a roll-to-roll electroless plating system **200** for use with exemplary embodiments of the invention. The roll-to-roll electroless plating system **200** includes a tank **230** of plating solution **210**. Web of media **250** is fed by a web advance system along a web transport path in an in-track direction **205** from a supply roll **202** to a take-up roll **204**. The web of media **250** is a substrate upon which electroless plating is to be performed. Drive rollers **206** advance the web of media **250** from the supply roll **202** through the tank of plating solution **210** to the take-up roll **204**. Web-guiding rollers **208** are at least partially submerged in the plating solution **210** in the tank **230** and guide the web of media **250** in an in-track direction **205**.

[0045] As the web of media **250** is advanced through the plating solution **210** in the tank **230**, a metallic plating substance such as copper, silver, gold, nickel or palladium is electrolessly plated from the plating solution **210** onto predetermined locations on one or both of a first surface **251** and a second surface **252** of the web of media **250**. As a result, the concentration of the metal or other components in the plating solution **210** in the tank **230** decreases and the plating solution **210** needs to be refreshed. To refresh the plating solution **210**, it is recirculated by pump **240**, and replenished plating solution **215** from a reservoir **220** is added under the control of controller **242**, which can include a valve (not shown). In the example shown in FIG. **3**, plating solution **210** is moved from tank **230** to pump **240** through a drain pipe **232** and is returned from pump **240** to tank **230** through a return pipe **234**. In order to remove particulates from plating solution **210**, a filter **236** can be included downstream of the pump **240**.

[0046] FIG. **4** illustrates one way to mount a submerged web-guiding roller **260** in a tank **230** of plating solution **210** in a roll-to-roll electroless plating system **200**. Web-guiding roller **260** includes shafts **262** at both ends supported by supports **264**. In some embodiments, the supports **264** can be attached to a wall of the tank **230**. The supports **264** include a hole **266** into which shaft **262** is inserted, providing corresponding bearing surfaces **268**. Both the web-guiding roller **260** and shaft **262** rotate together as indicated by the curved arrows. A potential problem with this way of mounting a roller submerged in plating solution **210** is that there is no driving force to cause plating solution **210** to flow past the bearing surfaces **268** of shaft **262** and hole **266**. As a result, metal can be plated out on the bearing surfaces of shaft **262** and hole **266**. As the metal plating builds up, friction can increase, which can cause the bearing to freeze up.

[0047] FIG. **5** is a schematic view of a web-guiding roller **270** for use in roll-to-roll electroless plating system **200** according to an exemplary embodiment of the invention. Web-guiding roller **270** is submerged in a tank **230** of plating solution **210**. Web-guiding roller **270** includes an axial recess **272** in end **271** of the web-guiding roller **270**. The axial recess **272** is "axial" in the sense that it shares a common axis with the web-guiding roller **270**. A roller mount **269** for supporting the web-guiding roller **270** while allowing its free rotation in this embodiment includes a non-rotating hollow shaft **275** that is disposed coaxially within the axial recess **272** of the web-guiding roller **270**. The roller mount **269** and axial recess **272** are only shown at one end of the web-guiding roller **270** in FIG. **5** for simplicity. Typically, a similar bearing arrangement would also be used at the other end of the web-guiding roller **270** as well.

[0048] Axial recess **272** is preferably cylindrical, and has a cylindrical recess surface **274** with a recess diameter D_1. Hollow shaft **275** has an inner surface **277** and a cylindrical outer surface **276** with an outer shaft diameter D_2. Recess diameter D_1 is slightly greater than outer shaft diameter D_2 so that there is clearance between the cylindrical outer surface **276** of hollow shaft **275** and the cylindrical recess surface **274** of axial recess **272**. In an exemplary embodiment, the difference between the diameters is approximately $D_1-D_2\approx1.0$ mm. The differences between the diameters is preferably in the range of about 0.5 mm$\leq D_1-D_2\leq$3.0 mm. Web-guiding roller **270** rotates freely around hollow shaft **275** with recess surface **274** of axial recess **272** being the bearing surface of the web-guiding roller **270**, and with outer surface **276** of the hollow shaft **275** being the bearing surface of the roller mount **269**.

[0049] Hollow shaft **275** can be a continuation of return pipe **234** or can be connected to return pipe **234**. In the exemplary embodiment illustrated in FIG. **5**, the hollow shaft **275** is shown as having the same outer diameter D_2 as the return pipe **234**, but in other embodiments (not shown) it can have a different diameter. In the illustrated configuration, the axial recess **272** is a blind hole having an end wall **278**. Plating solution **210** is pumped by pump **240** through the hollow shaft **275** in a plating solution flow direction **212** into the axial recess **272** of the submerged web-guiding roller **270**. The end wall **278** at the end of the axial recess **272** forces the plating solution **210** to flow back between the bearing surfaces, i.e. between cylindrical recess surface **274** of axial recess **272** and cylindrical outer surface **276** of the hollow shaft **275**, thereby providing a liquid bearing. The flow of the plating solution **210** inhibits electroless plating on the bearing surfaces of the hollow shaft **275** and the axial recess **272** of the web-guiding roller **270**. In some embodiments, the plating solution **210** that is pumped by pump **240** through the hollow shaft **275** and between the bearing surfaces of the web-guiding roller **270** and the roller mount **269** can be plating solution **210** drawn from the tank **230**. Alternatively the pump can draw replenished plating solution **215** from reservoir **220** under control of controller **242** and pump the replenished plating solution **215** through hollow shaft **275** and between the bearing surfaces. In still other instances, the liquid pumped through hollow shaft **275** and between the bearing surfaces is a mixture of plating solution **210** drawn from the tank **230** and replenished plating solution **215** drawn from the reservoir **220**.

[0050] In the illustrated configuration, all of the plating solution **210** from the pump **240** is shown as passing through the return pipe **234** into the hollow shaft **275**, and from there into the axial recess of the web-guiding roller **270**. In other embodiments, the hollow shaft **275** can be a branch off the return pipe **234**, and the return pipe **234** can also outlet into the tank **230** in order to return a portion of the plating solution **210** directly into the tank **230** similar to the configuration of FIG. **3**. This can be useful when the volume of plating solution **210** required to provide adequate replenishment is greater than that which can be pumped through the bearing. A filter **236** can also be used to filter the plating solution **210** as shown in FIG. **3**. Preferably the filter **236** would be positioned in the return pipe downstream of the pump **240**. The filter **236** can remove any contamination that might interfere with the performance of the bearing.

[0051] In the embodiment shown in FIG. **5**, plating solution **210** is pumped through the inside of the hollow shaft **275** and flows back between the bearing surfaces (cylindrical recess surface **274** and cylindrical outer surface **276**) after exiting the end of the hollow shaft **275** and hitting the end wall **278** of the axial recess **272**. FIG. **6** is a close-up perspective of the hollow shaft **275** according to another embodiment where the portion of the hollow shaft **275** that extends into the axial recess **272** (FIG. **5**) of the web-guiding roller **270** (FIG. **5**) has a plurality of holes **279** around the circumference of the hollow shaft **275**. The holes **279** enable plating solution **210** (not shown in FIG. **6**) which enters the hollow shaft **275** in plating solution flow direction **212** to pass outward from the inner surface **277** to the outer surface **276** of the hollow shaft **275** in radially outward direction **273**. With reference also to FIG. **5**, the hollow shaft **275** shown in FIG. **6** can provide plating solution **210** directly to the bearing surfaces (cylindrical recess surface **274** and cylindrical outer surface **276**) through the holes **279**. In FIG. **6**, shaft end **267** of hollow shaft **275** (the end that would be adjacent the end wall **278** when inserted into the axial recess **272**) is shown as being open, thereby allowing plating solution **210** to flow into the axial recess **272** through both the shaft end **267** and the holes **279**. Alternatively, the shaft end **267** could be closed so that all of the plating solution **210** is forced to exit the hollow shaft **275** through the holes **279**. In some embodiments, the size of the holes **279** can be varied along the length of the hollow shaft **275** to control the volume of plating solution that is injected along the length of the bearing surfaces.

[0052] FIG. **7** shows another embodiment where a web-guiding roller **290** includes a hollow cavity **292** that extends from an opening on a first end **291***a* to an opening on a second end **291***b* of the web-guiding roller **290**. Pump **240** pumps plating solution **210** through return pipe **234** into the hollow cavity **292** along plating solution flow direction **212** through hollow shafts **295** disposed within one or both of the openings on the first and second ends **291***a* and **291***b* of the web-guiding roller **290**. In the illustrated embodiment, the hollow cavity **292** has a cylindrical cavity surface **294** having a uniform diameter along the entire length of the hollow cavity **292**. In other embodiments, the diameter of the hollow cavity **292** may vary along its length, or may only be cylindrical along those portions of the hollow cavity **292** which serve as bearing surfaces. The hollow shafts **295** have cylindrical outer surfaces **296**. As was discussed earlier with respect to FIG. **5**, the diameter of cylindrical cavity surface **294** is slightly larger than the diameter of the cylindrical outer surfaces **296** in the portions of the hollow cavity **292** which serve as bearing surfaces. The plating solution **210** passes out of the hollow cavity **292** between the cylindrical cavity surface **294**, which is the bearing surface of the web-guiding roller **290**, and the cylindrical outer surfaces **296** of the hollow shafts **295**, which are the bearing surfaces of the roller mounts **269**. In the illustrated embodiment, the pump **240** draws plating solution **210** from the tank **230** through drain pipe **232**. In other embodiments, the pump **240** can also draw replenished plating solution **215** from a reservoir **220** (not shown in FIG. **7**) as was discussed with reference to FIG. **5**.

[0053] In the embodiments described above the hollow shaft **275**, **295** carrying plating solution **210** extends into an axial recess **272** or a hollow cavity **292** in a web-guiding roller **270**, **290**. FIG. **8** shows close-up perspective of an alternate embodiment of a roller mount where web-guiding roller **280** includes an axial shaft **282** protruding from an end **281** of the web-guiding roller **280**. The axial shaft **282** is "axial" in the sense that it shares a common axis with the web-guiding roller **280**. The axial shaft **282** is disposed within a hollow shaft **285**, which serves as the roller mount **269**, and rotates within the hollow shaft **285**.

[0054] The plating solution **210** is pumped into the hollow shaft **285** in plating solution flow direction. As with the embodiments described earlier, the plating solution **210** is then forced to flow between bearing surfaces on the web-guiding roller **280** and the roller mount **269** (i.e., hollow shaft **285**), to provide a liquid bearing, thereby inhibiting plating on the bearing surfaces. In further detail, axial shaft **282** has a cylindrical outer surface **284** with an axial shaft diameter D_3, and the hollow shaft **285** has a cylindrical inner surface **287** with an inner diameter D_4, where D_3 is slightly less than D_4. The outer surface **284** of the axial shaft **282** is the bearing surface of the web-guiding roller **280**, and the inner surface **287** of the hollow shaft **285** is the bearing surface of the roller mount **269**. In an exemplary embodiment, the difference between the diameters is approximately $D_4-D_3\approx1.0$ mm. The differences between the diameters is preferably in the range of about $0.5\text{ mm}\leq D_4-D_3\leq3.0\text{ mm}$.

[0055] As described above with reference to FIG. **5**, pump **240** can draw plating solution **210** from tank **230** or it can draw replenished plating solution **215** from reservoir **220**. In either case, the plating solution **210** or **215** is pumped through the hollow shaft **285** so that the plating solution **210** or **215** passes between the bearing surface of the web-guiding roller **280** (i.e., outer surface **284** of the axial shaft **282**) and the bearing surface of the roller mount **269** (i.e., inner surface **287** of the hollow shaft **285**), thereby providing a liquid bearing and inhibiting electroless plating on the bearing surfaces.

[0056] Recirculating lubricant past the bearing surfaces of an apparatus is known (for example, see U.S. Patent Application Publication 2013/0309340 to Day, entitled "Lubrication of bearing and roller shaft in pellet mill machines"). A significant difference in the present invention is that plating solution **210** is not an additional lubricant, but rather is a working fluid that the web-guiding roller **260**, **270**, **280** is submerged in to perform the electroless plating operation. Pumping a lubricant that is not the plating solution **210** past the bearing surfaces would contaminate the plating solution. Furthermore, the fact that the web-guiding roller **260**, **270**, **280** is submerged in an electroless plating solution **210** presents an additional problem due to the tendency for the plating solution **210** to plate out on the bearing surfaces. The inventors have discovered that pumping the plating solution **210** past the bearing surfaces mitigates this effect and substantially reduces the amount of material that is plated out on the bearing surface, while providing the necessary bearing lubrication.

[0057] FIG. **9** shows a high-level system diagram for an apparatus **400** having a touch screen **410** including a display device **420** and a touch sensor **430** that overlays at least a portion of a viewable area of display device **420**. Touch sensor **430** senses touch and conveys electrical signals (related to capacitance values for example) corresponding to the sensed touch to a controller **480**. Touch sensor **430** is an example of an article that can be printed on one or both sides by the flexographic printing system **100** (FIG. **2**) and plated using an embodiment of roll-to-roll electroless plating system **200** having a submerged web-guiding roller **270**, **280**, **290** as described above in FIGS. **5**-**8**.

[0058] FIG. **10** shows a schematic side view of a touch sensor **430**. Transparent substrate **440**, for example polyethylene terephthalate, has a first conductive pattern **450** printed and plated on a first side **441**, and a second conductive pattern **460** printed and plated on a second side **442**. The length and width of the transparent substrate **440**, which is cut from the take-up roll **104** (FIG. **2**), is not larger than the flexographic printing plates **112**, **122**, **132**, **142** of flexographic printing system **100** (FIG. **1**), but it could be smaller than the flexographic printing plates **112**, **122**, **132**, **142**.

[0059] FIG. **11** shows an example of a conductive pattern **450** that can be printed on first side **441** (FIG. **10**) of substrate **440** (FIG. **10**) using one or more print modules such as print modules **120** and **140** of flexographic printing system (FIG. **2**), followed by plating using an embodiment of roll-to-roll electroless plating system **200** as described above. Conductive pattern **450** includes a grid **452** including grid columns **455** of intersecting fine lines **451** and **453** that are connected to an array of channel pads **454**. Interconnect lines **456** connect the channel pads **454** to the connector pads **458** that are connected to controller **480** (FIG. **9**). Conductive pattern **450** can be printed by a single print module **120** in some embodiments. However, because the optimal print conditions for fine lines **451** and **453** (e.g., having line widths on the order of 4 to 8 microns) are typically different than for printing the wider channel pads **454**, connector pads **458** and interconnect lines **456**, it can be advantageous to use one print module **120** for printing the fine lines **451** and **453** and a second print module **140** for printing the wider features. Furthermore, for clean intersections of fine lines **451** and **453**, it can be further advantageous to print and cure one set of fine lines **451** using one print module **120**, and to print and cure the second set of fine lines **453** using a second print module **140**, and to print the wider features using a third print module (not shown in FIG. **2**) configured similarly to print modules **120** and **140**.

[0060] FIG. **12** shows an example of a conductive pattern **460** that can be printed on second side **442** (FIG. **10**) of substrate **440** (FIG. **10**) using one or more print modules such as print modules **110** and **130** of flexographic printing system (FIG. **2**), followed by plating using an embodiment of roll-to-roll electroless plating system **200** as described above. Conductive pattern **460** includes a grid **462** including grid rows **465** of intersecting fine lines **461** and **463** that are connected to an array of channel pads **464**. Interconnect lines **466** connect the channel pads **464** to the connector pads **468** that are connected to controller **480** (FIG. **9**). In some embodiments, conductive pattern **460** can be printed by a single print module **110**. However, because the optimal print conditions for fine lines **461** and **463** (e.g., having line widths on the order of 4 to 8 microns) are typically different than for the wider channel pads **464**, connector pads **468** and interconnect lines **466**, it can be advantageous to use one print module **110** for printing the fine lines **461** and **463** and a second print module **130** for printing the wider features. Furthermore, for clean intersections of fine lines **461** and **463**, it can be further advantageous to print and cure one set of fine lines **461** using one print module **110**, and to print and cure the second set of fine lines **463** using a second print module **130**, and to print the wider features using a third print module (not shown in FIG. **2**) configured similarly to print modules **110** and **130**.

[0061] Alternatively, in some embodiments conductive pattern **450** can be printed using one or more print modules configured like print modules **110** and **130**, and conductive pattern **460** can be printed using one or more print modules configured like print modules **120** and **140** of FIG. **2** followed by plating using an embodiment of roll-to-roll electroless plating system **200** as described above.

[0062] With reference to FIGS. **9-12**, in operation of touch screen **410**, controller **480** can sequentially electrically drive grid columns **455** via connector pads **458** and can sequentially sense electrical signals on grid rows **465** via connector pads **468**. In other embodiments, the driving and sensing roles of the grid columns **455** and the grid rows **465** can be reversed.

[0063] The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

[0064] **10** roll-to-roll electroless plating system
[0065] **20** pan
[0066] **25** side wall
[0067] **27** hole
[0068] **30** sump
[0069] **40** web-guiding roller
[0070] **45** shaft
[0071] **50** bearing
[0072] **65** drop
[0073] **70** pump
[0074] **100** flexographic printing system
[0075] **102** supply roll
[0076] **104** take-up roll
[0077] **105** roll-to-roll direction
[0078] **106** roller
[0079] **107** roller
[0080] **110** print module
[0081] **111** plate cylinder
[0082] **112** flexographic printing plate
[0083] **113** raised features
[0084] **114** impression cylinder
[0085] **115** anilox roller
[0086] **116** UV curing station
[0087] **120** print module
[0088] **121** plate cylinder
[0089] **122** flexographic printing plate
[0090] **124** impression cylinder
[0091] **125** anilox roller
[0092] **126** UV curing station
[0093] **130** print module
[0094] **131** plate cylinder
[0095] **132** flexographic printing plate
[0096] **134** impression cylinder
[0097] **135** anilox roller
[0098] **136** UV curing station
[0099] **140** print module
[0100] **141** plate cylinder
[0101] **142** flexographic printing plate
[0102] **144** impression cylinder
[0103] **145** anilox roller
[0104] **146** UV curing station
[0105] **150** substrate
[0106] **151** first side
[0107] **152** second side
[0108] **200** roll-to-roll electroless plating system
[0109] **202** supply roll
[0110] **204** take-up roll
[0111] **205** in-track direction
[0112] **206** drive roller
[0113] **208** web-guiding roller
[0114] **210** plating solution
[0115] **212** plating solution flow direction
[0116] **215** replenished plating solution
[0117] **220** reservoir
[0118] **230** tank
[0119] **232** drain pipe
[0120] **234** return pipe
[0121] **236** filter
[0122] **240** pump
[0123] **242** controller
[0124] **250** web of media
[0125] **251** first surface
[0126] **252** second surface
[0127] **260** web-guiding roller
[0128] **262** shaft
[0129] **264** support
[0130] **267** shaft end
[0131] **266** hole
[0132] **268** bearing surfaces
[0133] **269** roller mount
[0134] **270** web-guiding roller
[0135] **271** end
[0136] **272** axial recess
[0137] **273** radially outward direction
[0138] **274** recess surface
[0139] **275** hollow shaft
[0140] **276** outer surface
[0141] **277** inner surface
[0142] **278** end wall
[0143] **279** holes
[0144] **280** web-guiding roller
[0145] **281** end
[0146] **282** axial shaft
[0147] **284** outer surface
[0148] **285** hollow shaft
[0149] **287** inner surface
[0150] **290** web-guiding roller
[0151] **291***a* first end
[0152] **291***b* second end
[0153] **292** hollow cavity
[0154] **294** cavity surface
[0155] **295** hollow shaft
[0156] **296** outer surface
[0157] **400** apparatus
[0158] **410** touch screen
[0159] **420** display device
[0160] **430** touch sensor
[0161] **440** transparent substrate
[0162] **441** first side
[0163] **442** second side
[0164] **450** conductive pattern
[0165] **451** fine lines
[0166] **452** grid
[0167] **453** fine lines
[0168] **454** channel pads
[0169] **455** grid column
[0170] **456** interconnect lines

[0171] **458** connector pads

[0172] **460** conductive pattern

[0173] **461** fine lines

[0174] **462** grid

[0175] **463** fine lines

[0176] **464** channel pads

[0177] **465** grid row

[0178] **466** interconnect lines

[0179] **468** connector pads

[0180] **480** controller

[0181] D_1 recess diameter

[0182] D_2 shaft diameter

[0183] D_3 shaft diameter

[0184] D_4 inner diameter

1. A roll-to-roll electroless plating system, comprising:

a tank containing a plating solution;

a web advance system for advancing a web of media in an in-track direction along a web transport path from an input roll through the plating solution in the tank to a take-up roll, wherein a plating substance in the plating solution is plated onto predetermined locations on a surface of the web of media as it is advanced through the plating solution in the tank, and wherein the web advance system includes:

a web-guiding roller for guiding the web of media, the web-guiding roller being at least partially submerged within the plating solution in the tank; and

a roller mount for supporting the web-guiding roller while allowing free rotation of the web-guiding roller, wherein the web-guiding roller and the roller mount include corresponding bearing surfaces; and

a pump configured to cause plating solution to flow between the bearing surface of the web-guiding roller and the bearing surface of the roller mount.

2. The roll-to-roll electroless plating system of claim **1**, wherein the web-guiding roller includes an axial recess in an end of the web-guiding roller, and the roller mount includes a non-rotating hollow shaft that is disposed within the axial recess of the web-guiding roller, and wherein the web-guiding roller rotates around the hollow shaft.

3. The roll-to-roll electroless plating system of claim **2**, wherein the axial recess is cylindrical and has a cylindrical recess surface with a recess diameter, and the hollow shaft has an inner surface and a cylindrical outer surface with an outer shaft diameter, the recess diameter of the axial recess being greater than the outer shaft diameter of the hollow shaft, and wherein the cylindrical recess surface of the axial recess is the bearing surface of the web-guiding roller and the cylindrical outer surface of the hollow shaft is the bearing surface of the roller mount.

4. The roll-to-roll electroless plating system of claim **3**, wherein the pump pumps plating solution through the hollow shaft and between the bearing surface of the web-guiding roller and the bearing surface of the roller mount.

5. The roll-to-roll electroless plating system of claim **4**, wherein the hollow shaft includes a plurality of holes around the circumference of the hollow shaft which enable plating solution to pass radially outward from the inner surface to the outer surface of the hollow shaft.

6. The roll-to-roll electroless plating system of claim **4** wherein the pump draws plating solution from the tank.

7. The roll-to-roll electroless plating system of claim **4**, wherein the pump draws plating solution from a reservoir to provide replenished plating solution.

8. The roll-to-roll electroless plating system of claim **1**, wherein the web-guiding roller includes an axial shaft protruding from an end of the web-guiding roller, and the roller mount includes a non-rotating hollow shaft, the axial shaft of the web-guiding roller being disposed within the hollow shaft, and wherein the axial shaft of the web-guiding roller rotates within the hollow shaft.

9. The roll-to-roll electroless plating system of claim **8**, wherein the axial shaft has a cylindrical outer surface with an axial shaft diameter, and the hollow shaft has a cylindrical inner surface with an inner diameter, the axial shaft diameter of the axial shaft being less than the inner diameter of the hollow shaft, and wherein the cylindrical outer surface of the axial shaft is the bearing surface of the web-guiding roller and the cylindrical inner surface of the hollow shaft is the bearing surface of the roller mount.

10. The roll-to-roll electroless plating system of claim **9**, wherein the pump pumps plating solution through the hollow shaft so that it passes between the bearing surface of the web-guiding roller and the bearing surface of the roller mount.

11. The roll-to-roll electroless plating system of claim **10** wherein the pump draws plating solution from the tank.

12. The roll-to-roll electroless plating system of claim **9**, wherein the pump draws plating solution from a reservoir to provide replenished plating solution.

13. The roll-to-roll electroless plating system of claim **1**, wherein the web-guiding roller includes a hollow cavity that extends from an opening on a first end of the web-guiding roller to an opening on a second end of the web-guiding roller, and wherein the plating solution is pumped into the hollow cavity through one or both of the openings on the first and second ends of the web-guiding roller and the plating solution passes out of the hollow cavity by passing between the bearing surface of the web-guiding roller and the bearing surface of the roller mount.

14. The roll-to-roll electroless plating system of claim **13**, wherein the roller mount includes a non-rotating hollow shaft that is disposed within the hollow cavity of the web-guiding roller, and wherein the web-guiding roller rotates around the hollow shaft.

15. The roll-to-roll electroless plating system of claim **14**, wherein the hollow cavity includes a cylindrical portion within which the hollow shaft is disposed, the cylindrical portion having a cylindrical cavity surface with a cavity diameter, and the hollow shaft having a cylindrical outer surface with an outer shaft diameter, the cavity diameter being greater than the outer shaft diameter, and wherein the cylindrical cavity surface of the cylindrical portion of the hollow shaft is the bearing surface of the web-guiding roller and the cylindrical outer surface of the hollow shaft is the bearing surface of the roller mount.

16. The roll-to-roll electroless plating system of claim **1**, further including a return pipe from the pump to the tank for recirculation of the plating solution.

17. The roll-to-roll electroless plating system of claim **1**, further including a filter disposed downstream of the pump.

18. The roll-to-roll electroless plating system of claim **1**, wherein the plating substance includes copper, silver, gold, nickel or palladium.

19. An article having features that were plated using the roll-to-roll electroless plating system of claim **1**.

20. The article of claim **19**, wherein at least some of the features have widths between 2 microns and 10 microns.

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