

FIG. 1 (Prior Art)

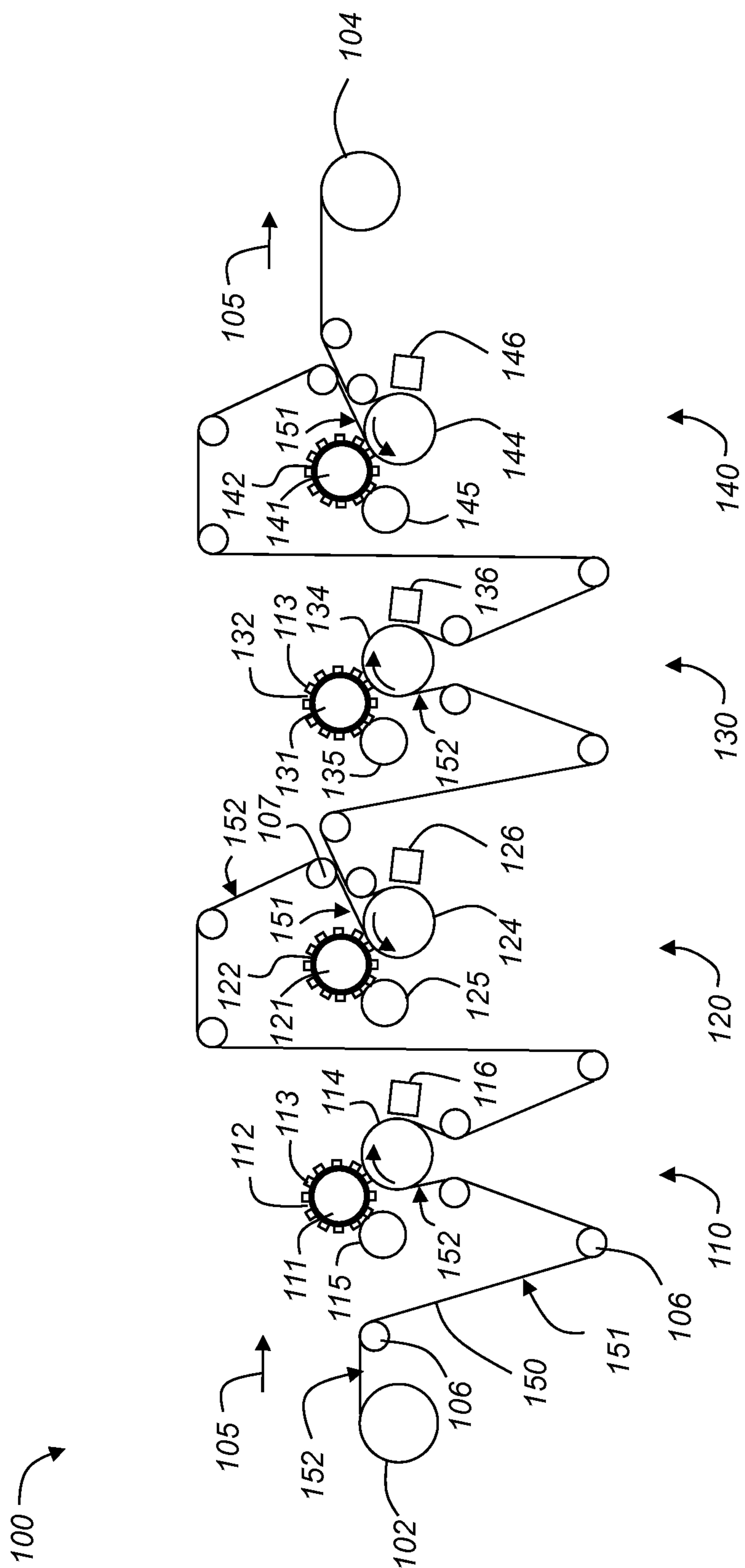


FIG. 2

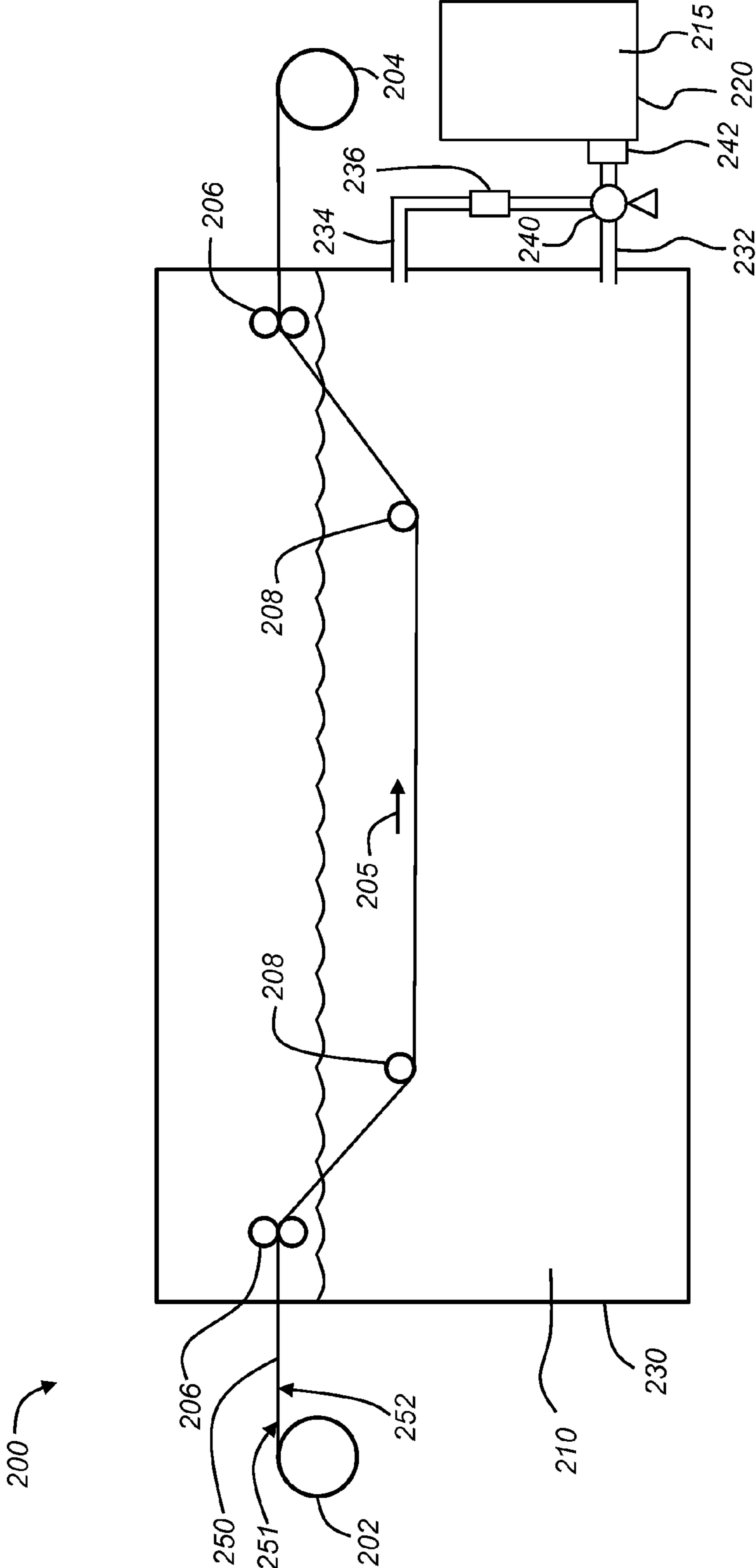


FIG. 3

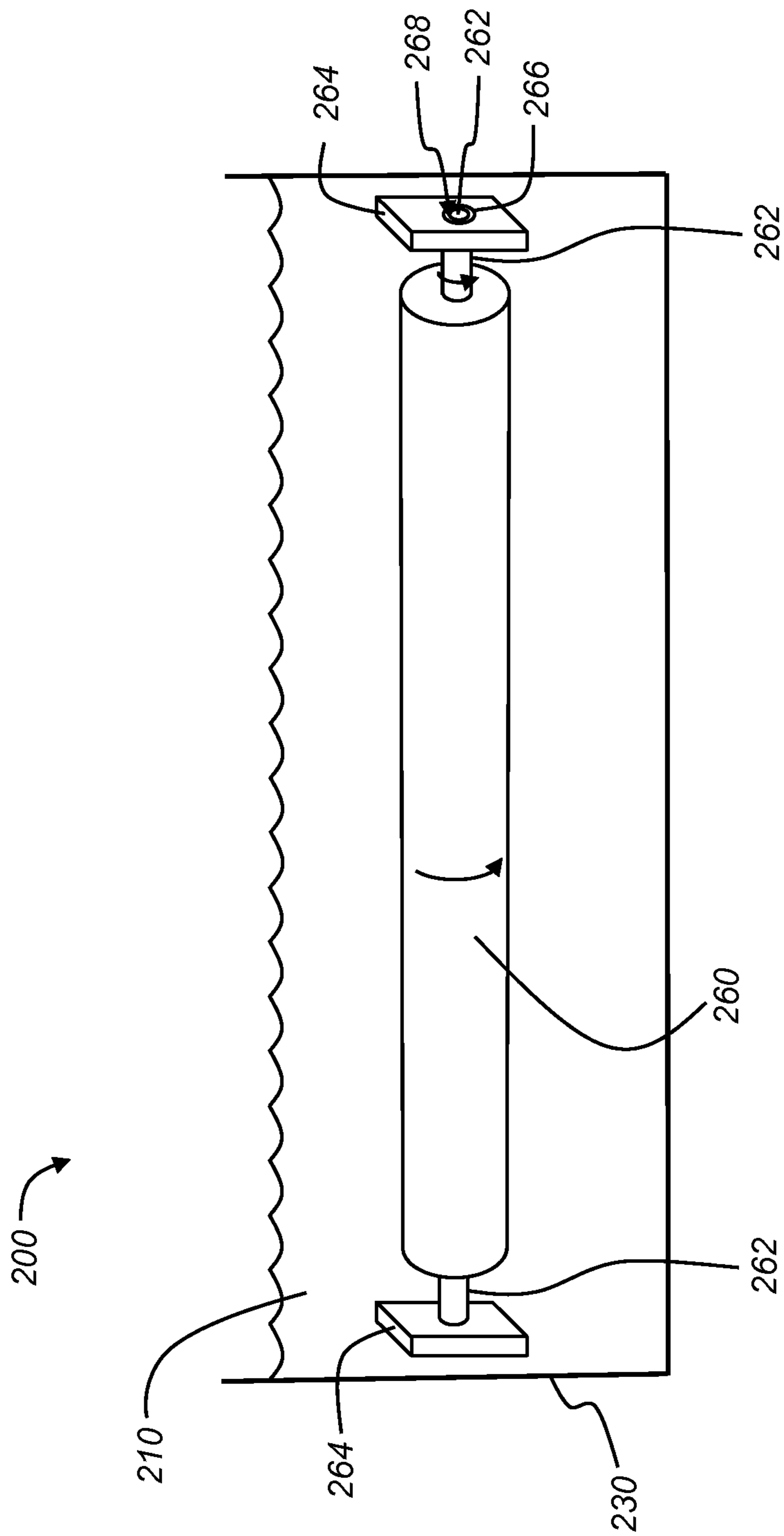


FIG. 4

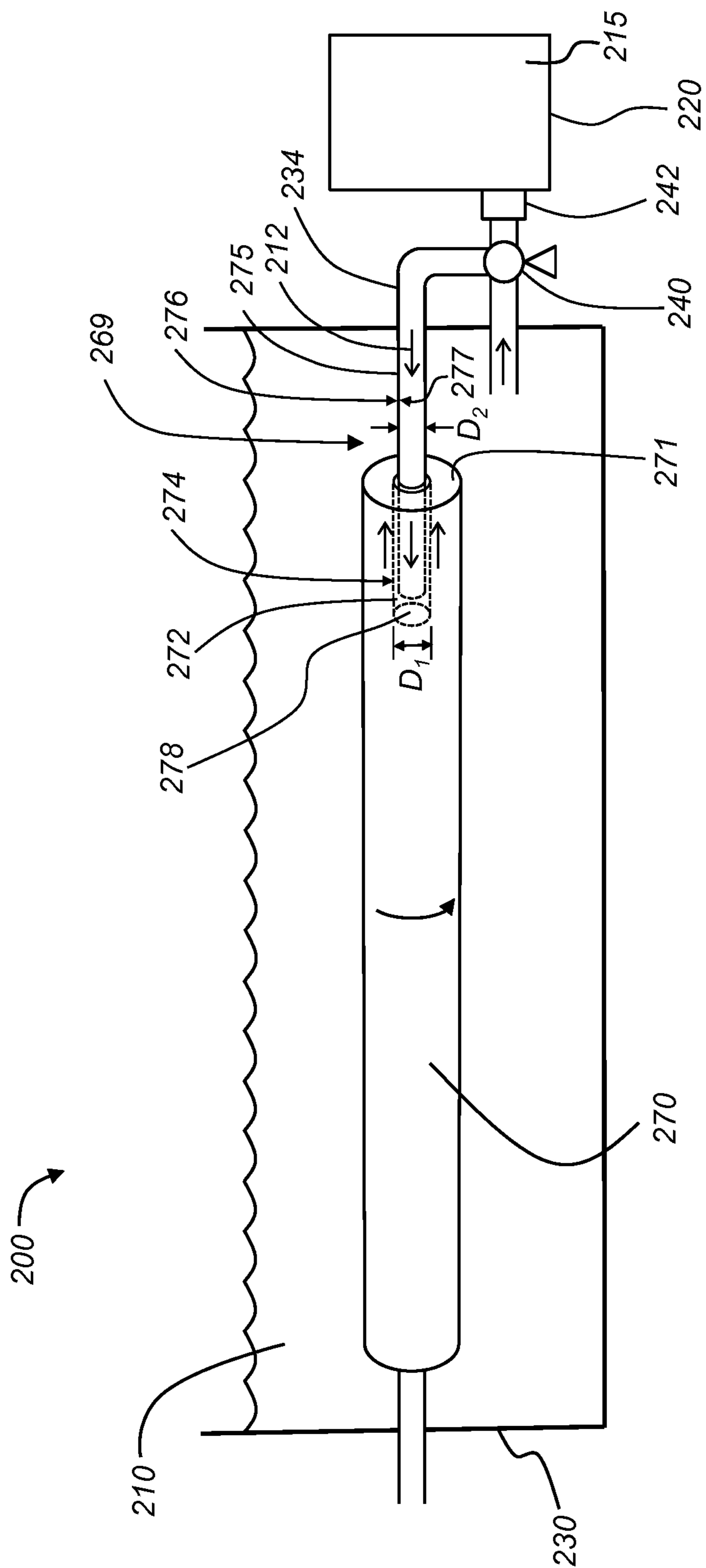


FIG. 5

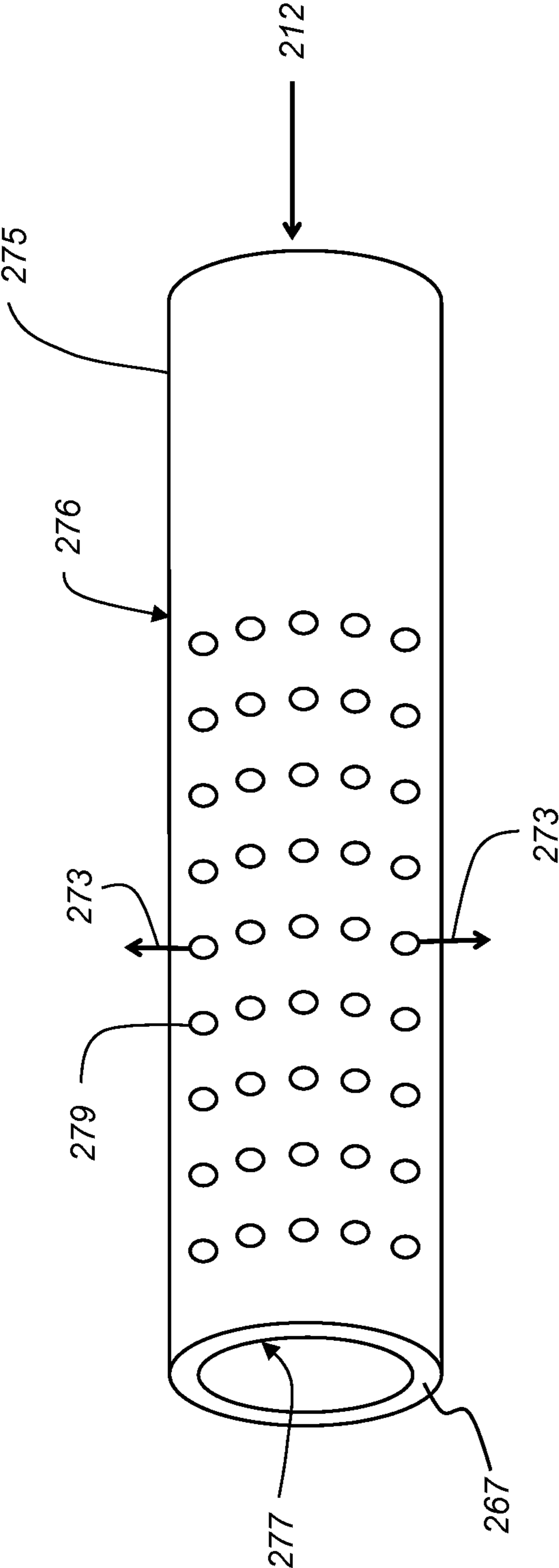


FIG. 6

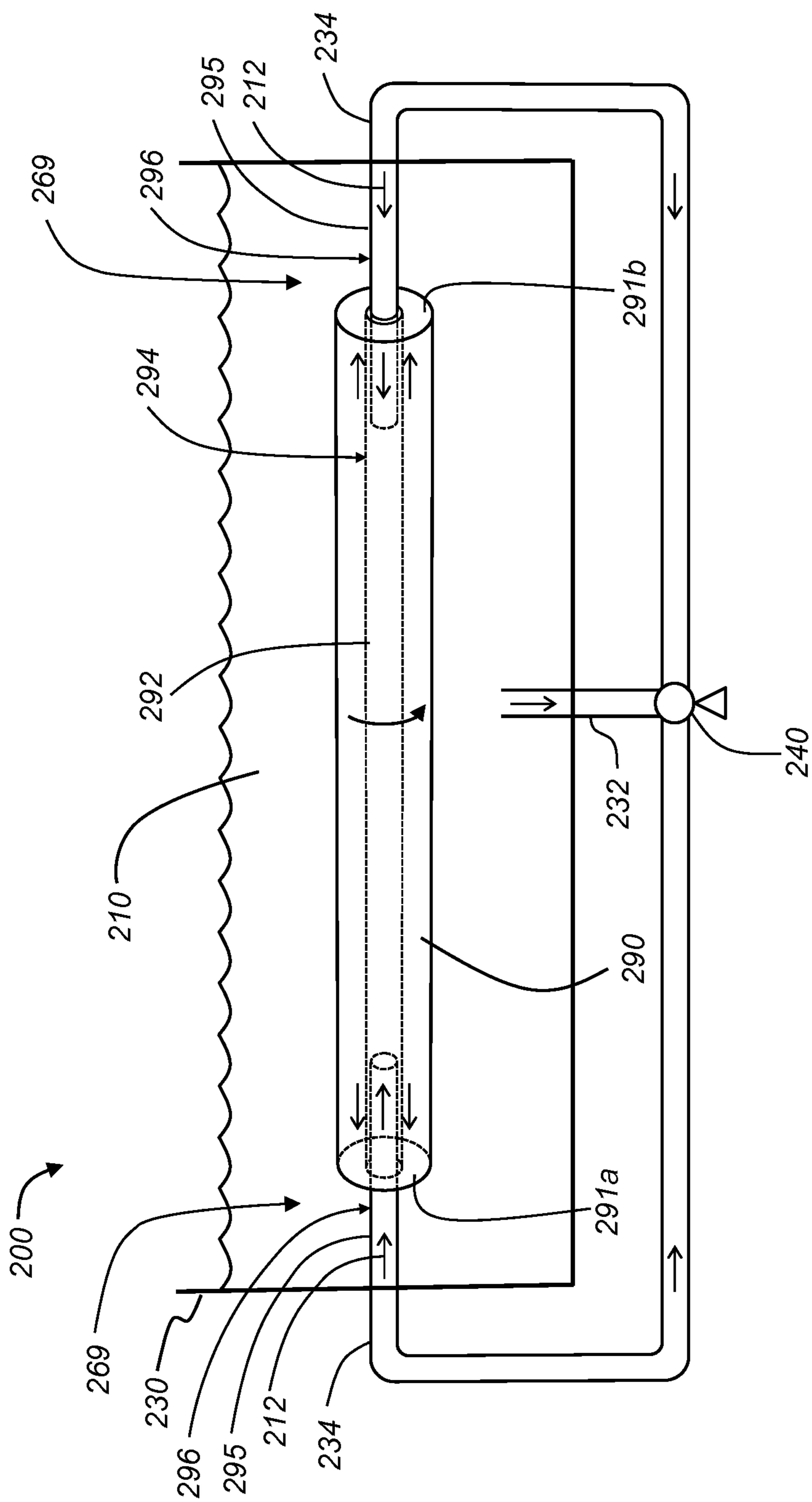


FIG. 7



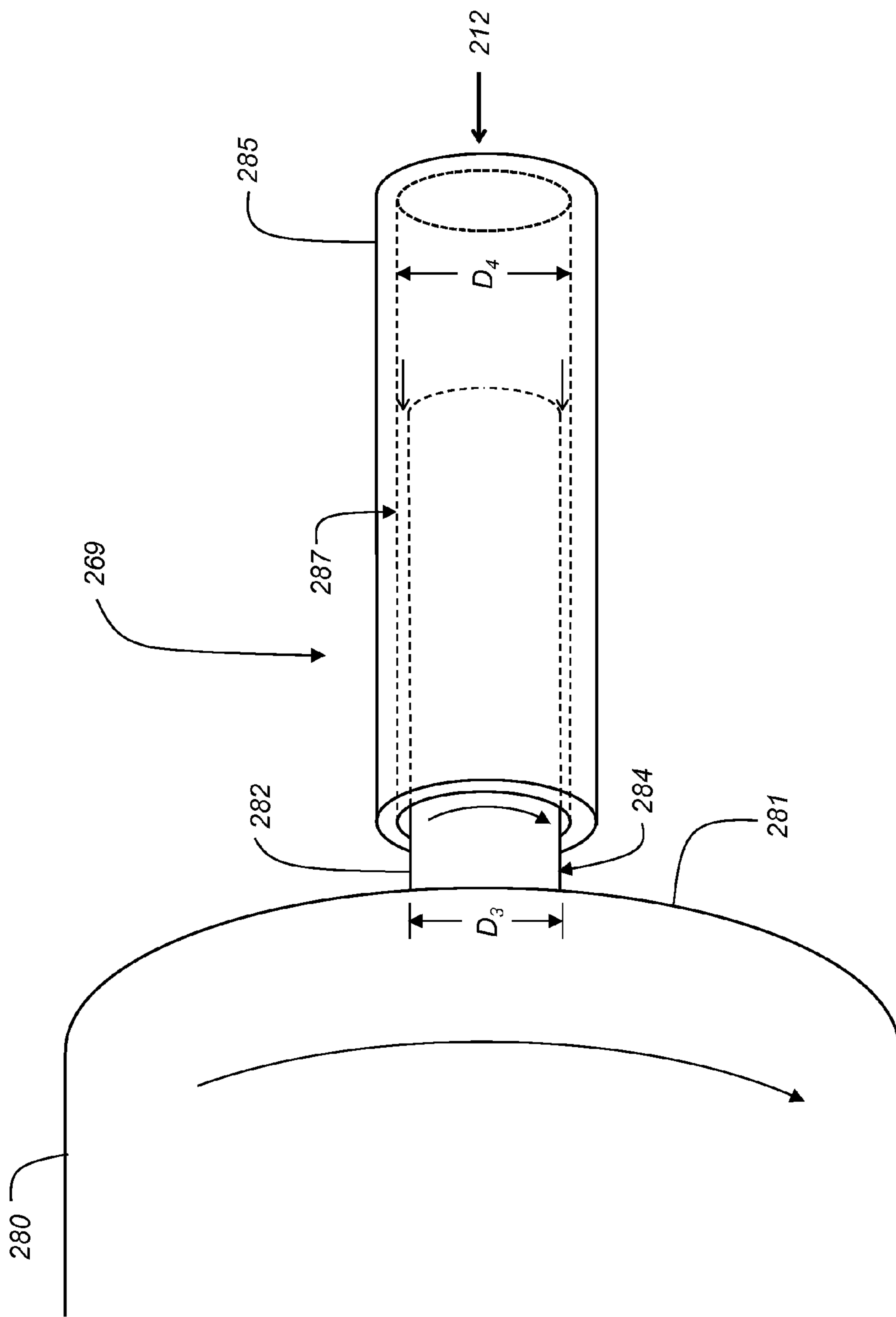
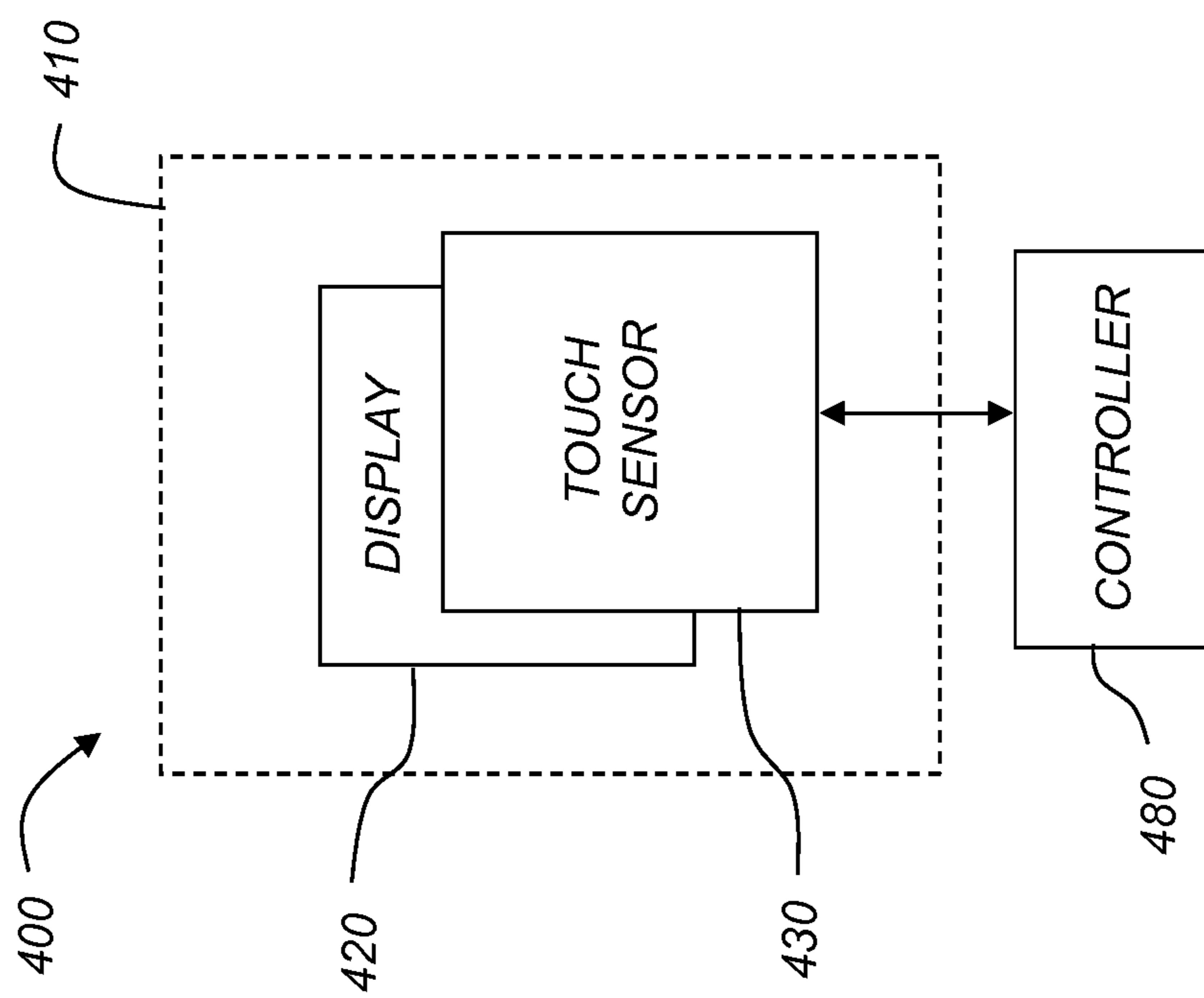
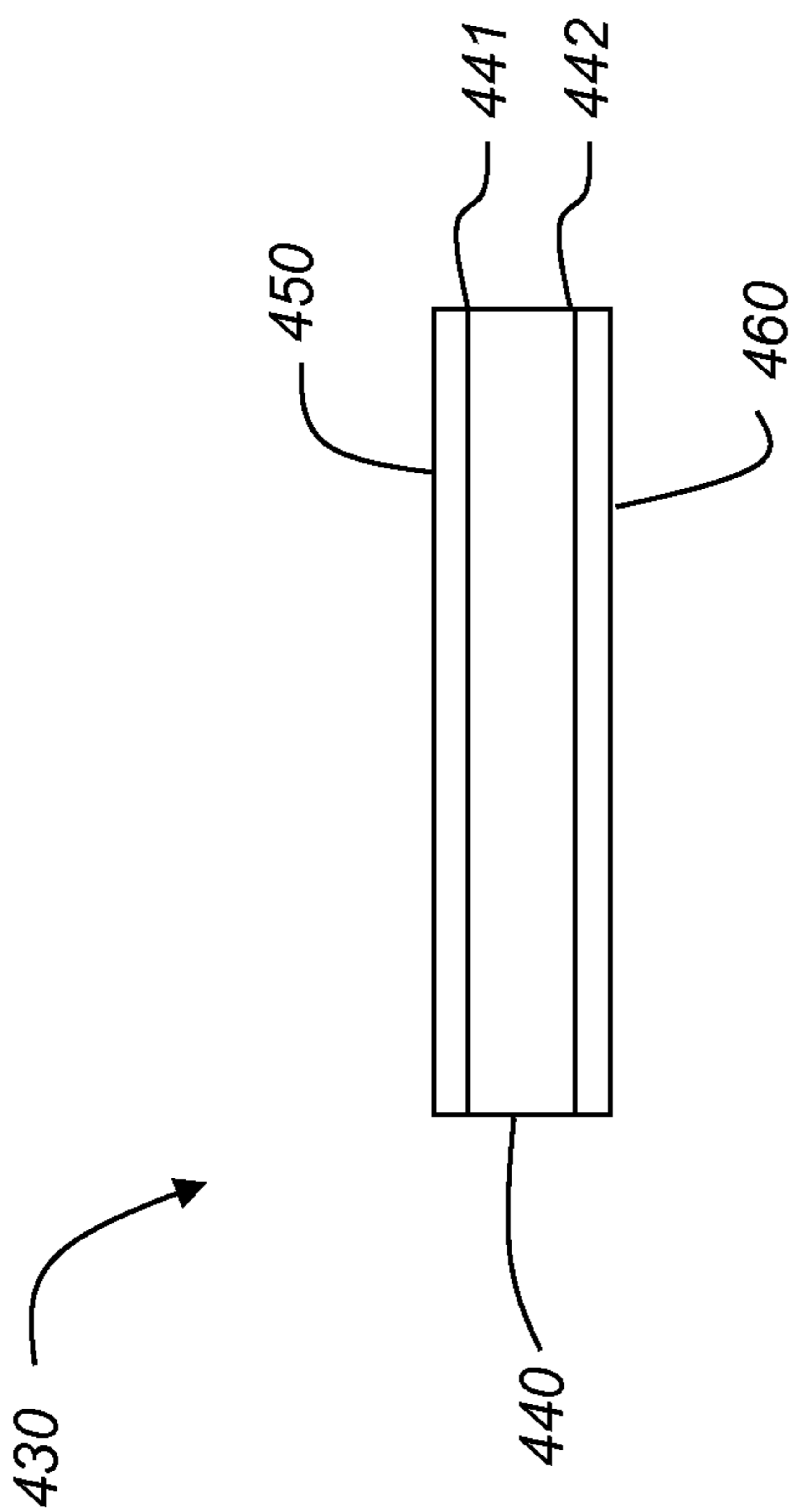


FIG. 8



**FIG. 9**



**FIG. 10**

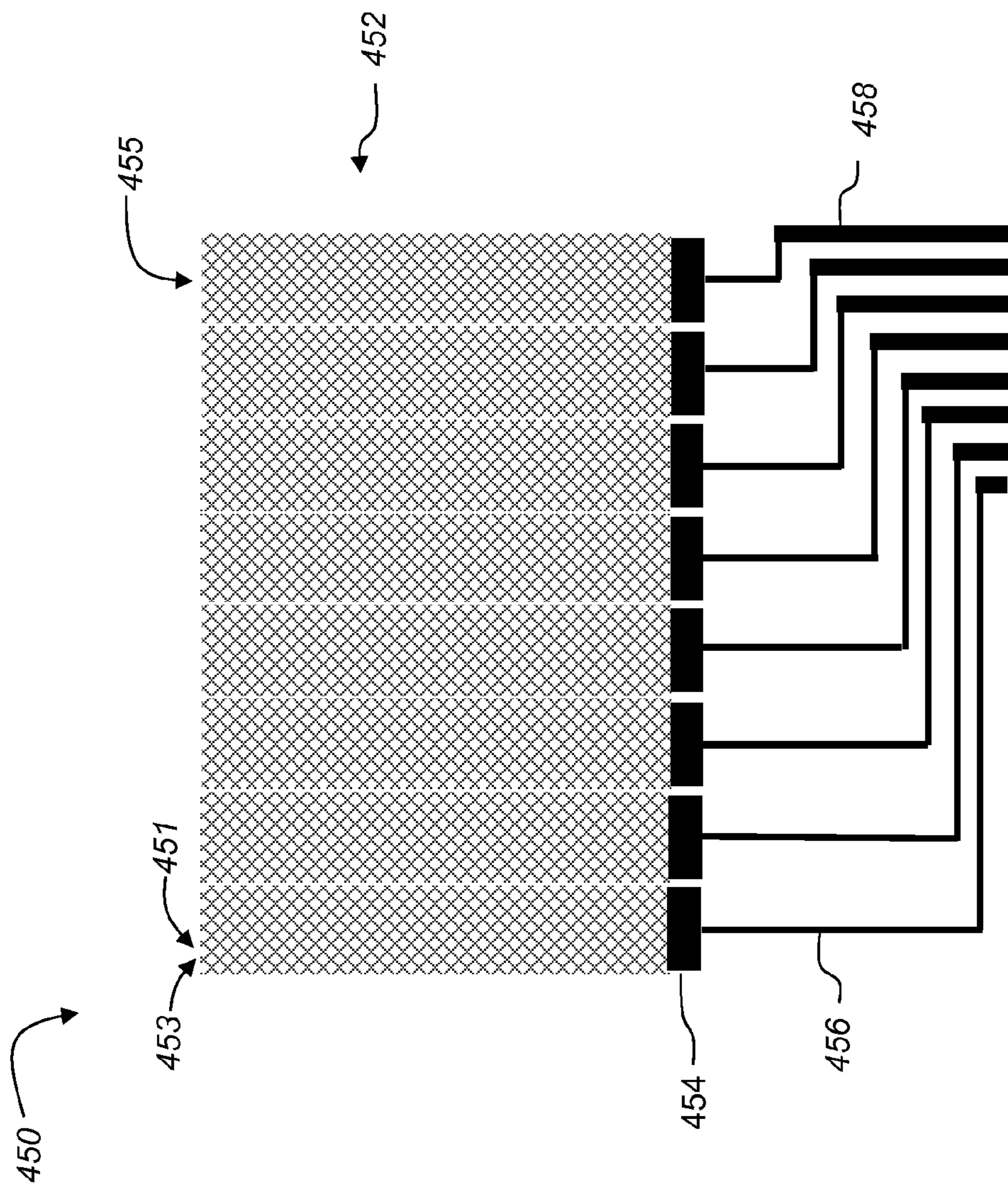


FIG. 11

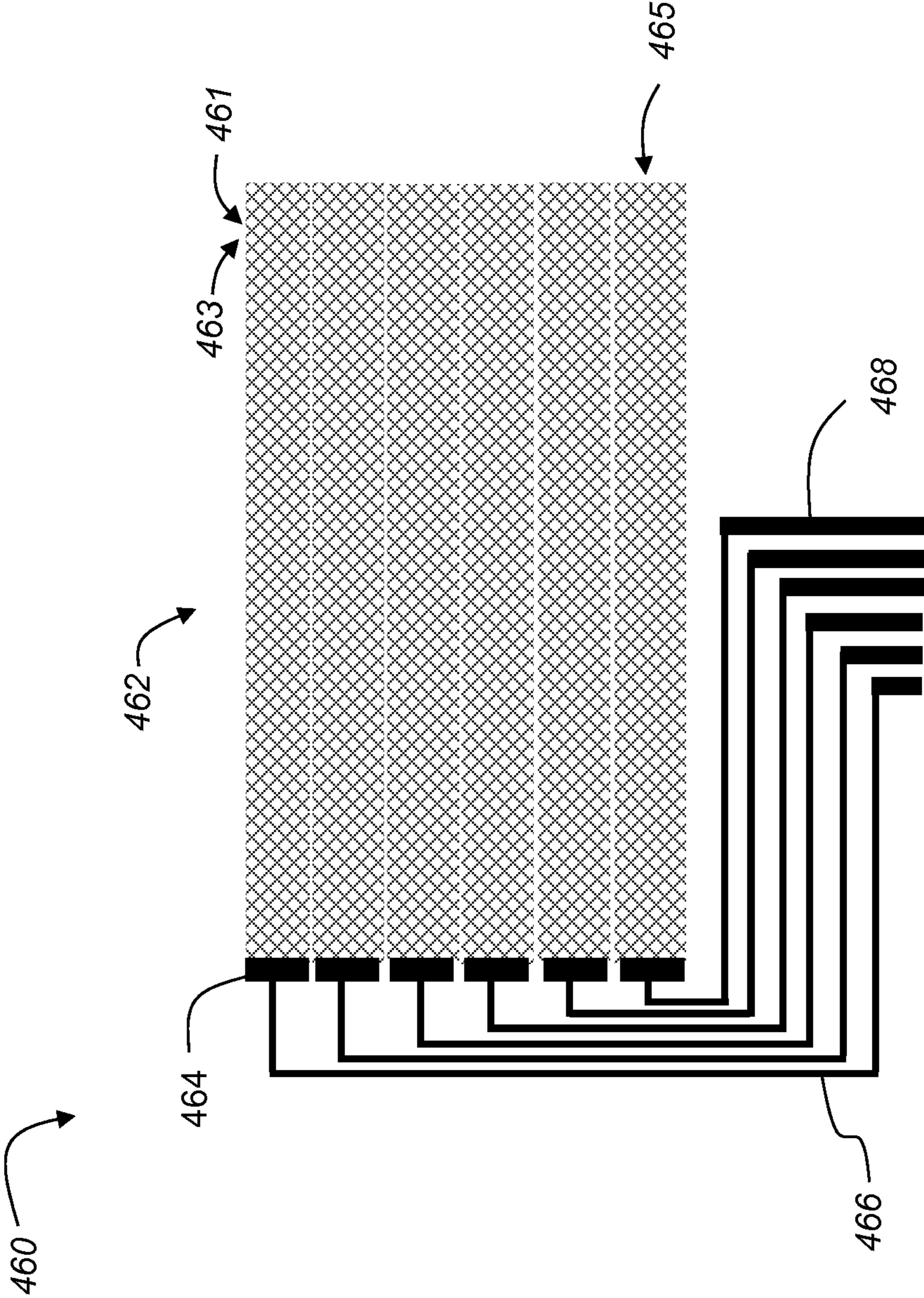


FIG. 12

## 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  $D_1 - D_2 \approx 1.0$  mm. The differences between the diameters is preferably in the range of about  $0.5 \text{ mm} \leq D_1 - D_2 \leq 3.0$  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 291a to an opening on a second end 291b 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 291a and 291b 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  $D_4 - D_3 \approx 1.0$  mm. The differences between the diameters is preferably in the range of about  $0.5 \text{ mm} \leq D_4 - D_3 \leq 3.0$  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	[0107]	152	second side
[0065]	20	pan	[0108]	200	roll-to-roll electroless plating system
[0066]	25	side wall	[0109]	202	supply roll
[0067]	27	hole	[0110]	204	take-up roll
[0068]	30	sump	[0111]	205	in-track direction
[0069]	40	web-guiding roller	[0112]	206	drive roller
[0070]	45	shaft	[0113]	208	web-guiding roller
[0071]	50	bearing	[0114]	210	plating solution
[0072]	65	drop	[0115]	212	plating solution flow direction
[0073]	70	pump	[0116]	215	replenished plating solution
[0074]	100	flexographic printing system	[0117]	220	reservoir
[0075]	102	supply roll	[0118]	230	tank
[0076]	104	take-up roll	[0119]	232	drain pipe
[0077]	105	roll-to-roll direction	[0120]	234	return pipe
[0078]	106	roller	[0121]	236	filter
[0079]	107	roller	[0122]	240	pump
[0080]	110	print module	[0123]	242	controller
[0081]	111	plate cylinder	[0124]	250	web of media
[0082]	112	flexographic printing plate	[0125]	251	first surface
[0083]	113	raised features	[0126]	252	second surface
[0084]	114	impression cylinder	[0127]	260	web-guiding roller
[0085]	115	anilox roller	[0128]	262	shaft
[0086]	116	UV curing station	[0129]	264	support
[0087]	120	print module	[0130]	267	shaft end
[0088]	121	plate cylinder	[0131]	266	hole
[0089]	122	flexographic printing plate	[0132]	268	bearing surfaces
[0090]	124	impression cylinder	[0133]	269	roller mount
[0091]	125	anilox roller	[0134]	270	web-guiding roller
[0092]	126	UV curing station	[0135]	271	end
[0093]	130	print module	[0136]	272	axial recess
[0094]	131	plate cylinder	[0137]	273	radially outward direction
[0095]	132	flexographic printing plate	[0138]	274	recess surface
[0096]	134	impression cylinder	[0139]	275	hollow shaft
[0097]	135	anilox roller	[0140]	276	outer surface
[0098]	136	UV curing station	[0141]	277	inner surface
[0099]	140	print module	[0142]	278	end wall
[0100]	141	plate cylinder	[0143]	279	holes
[0101]	142	flexographic printing plate	[0144]	280	web-guiding roller
[0102]	144	impression cylinder	[0145]	281	end
[0103]	145	anilox roller	[0146]	282	axial shaft
[0104]	146	UV curing station	[0147]	284	outer surface
[0105]	150	substrate	[0148]	285	hollow shaft
[0106]	151	first side	[0149]	287	inner surface
			[0150]	290	web-guiding roller
			[0151]	291a	first end
			[0152]	291b	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.