



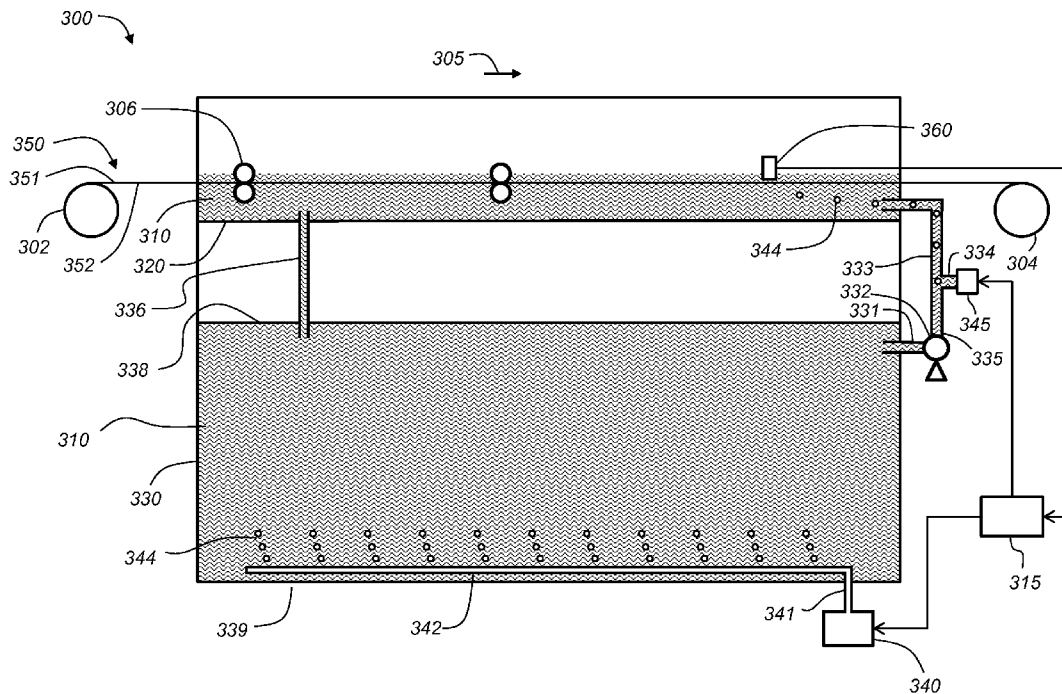
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(19) **United States**(12) **Patent Application Publication**
Wainwright et al.(10) **Pub. No.: US 2016/0040291 A1**(43) **Pub. Date: Feb. 11, 2016**(54) **ROLL-TO-ROLL ELECTROLESS PLATING
SYSTEM WITH MICRO-BUBBLE INJECTOR**(71) Applicants: **Gary P. Wainwright**, Fairport, NY (US);
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Shawn A. Reuter, Rochester, NY (US)(21) Appl. No.: **14/455,246**(22) Filed: **Aug. 8, 2014****Publication Classification**(51) **Int. Cl.**
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(57)

ABSTRACT

A roll-to-roll electroless plating system including a reservoir containing plating solution. A web advance system advances a web of media through the plating solution in the reservoir, wherein a plating substance in the plating solution is plated onto predetermined locations on a surface of the web of media. A distribution system injects an inert gas into the plating solution to reduce the amount of dissolved oxygen. The distribution system includes an injector having a converging tube segment, a diverging tube segment downstream of the converging tube segment, a throat formed at a junction of the converging tube segment and the diverging tube segment, and an inlet for the inert gas in proximity to the throat.



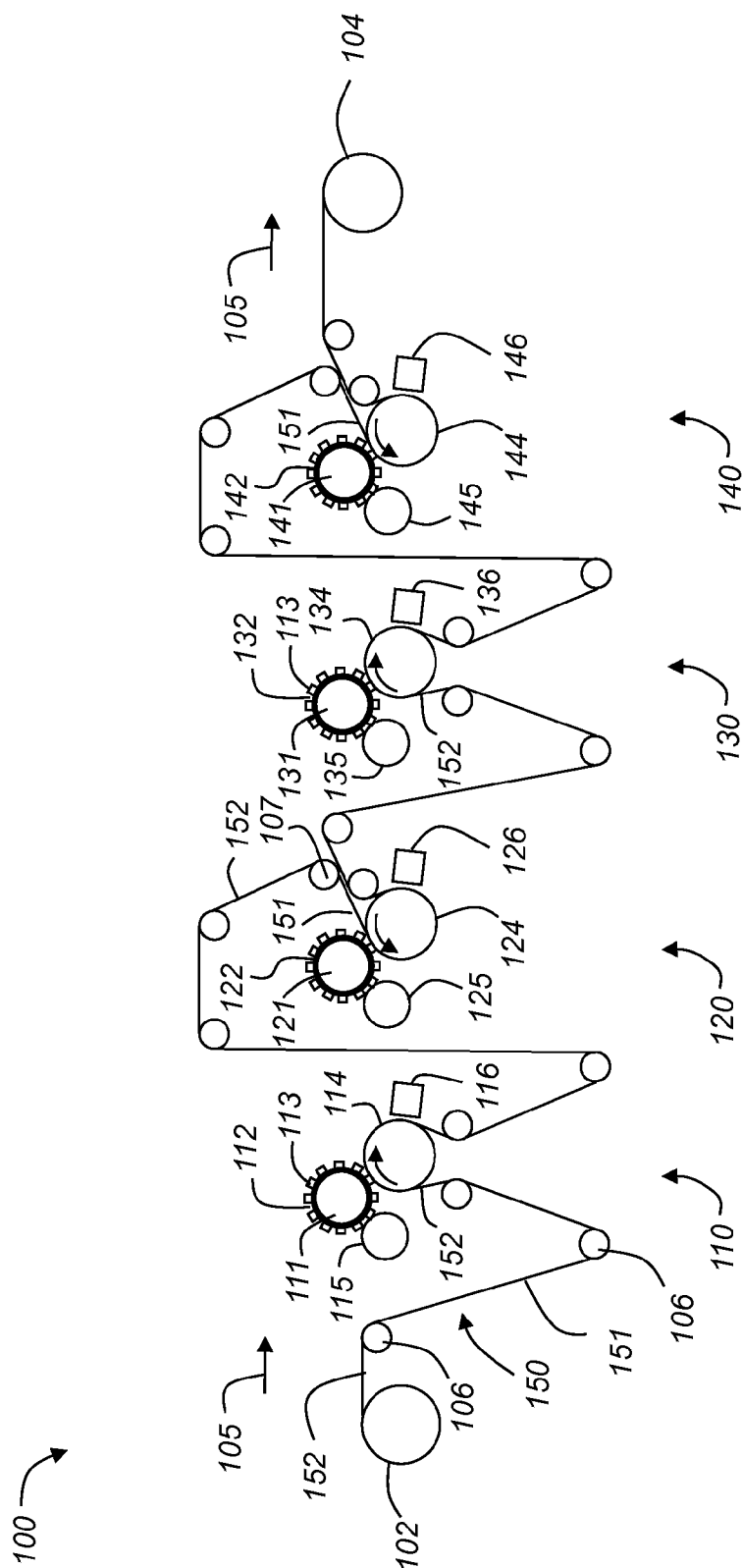


FIG. 1

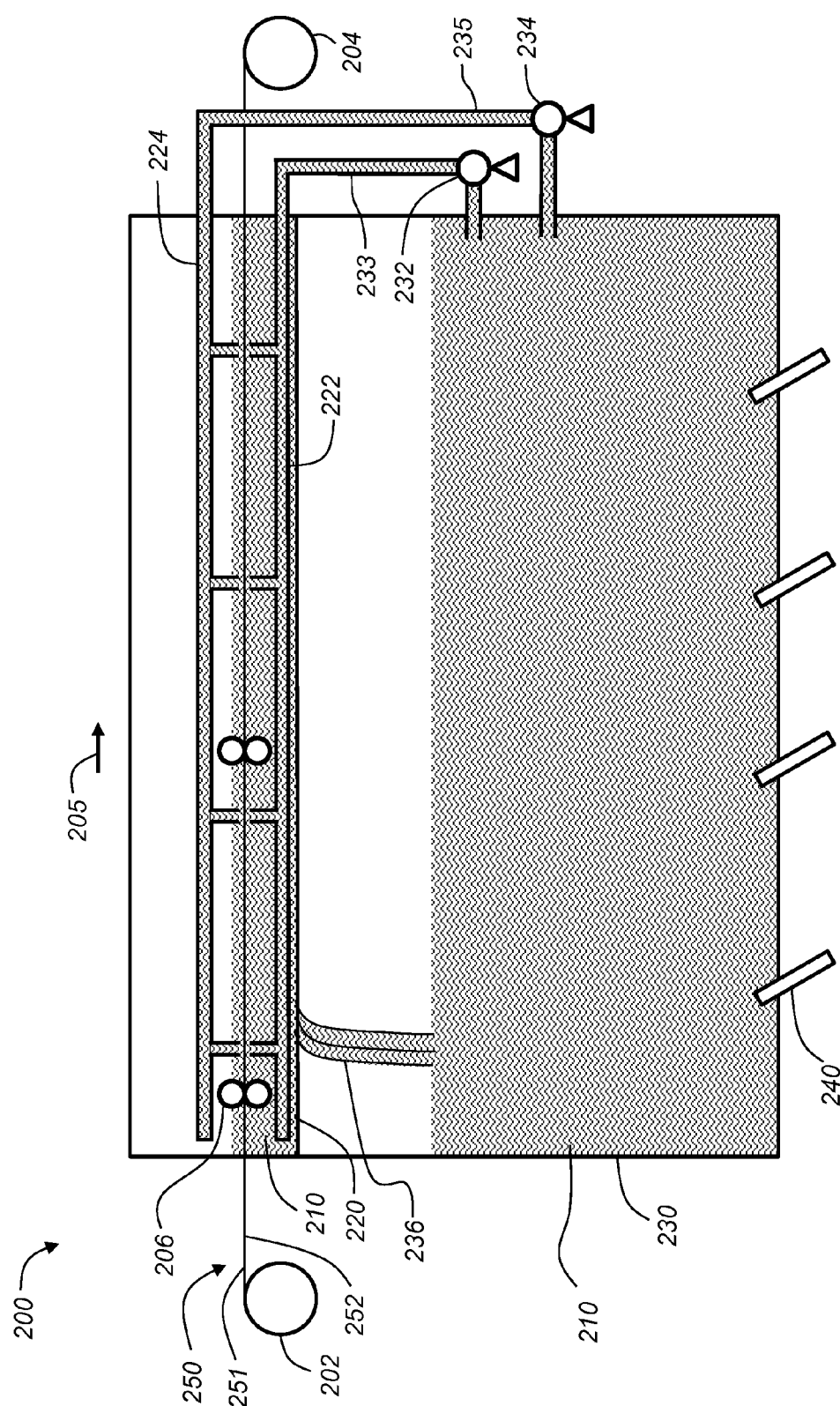


FIG. 2 (Prior Art)

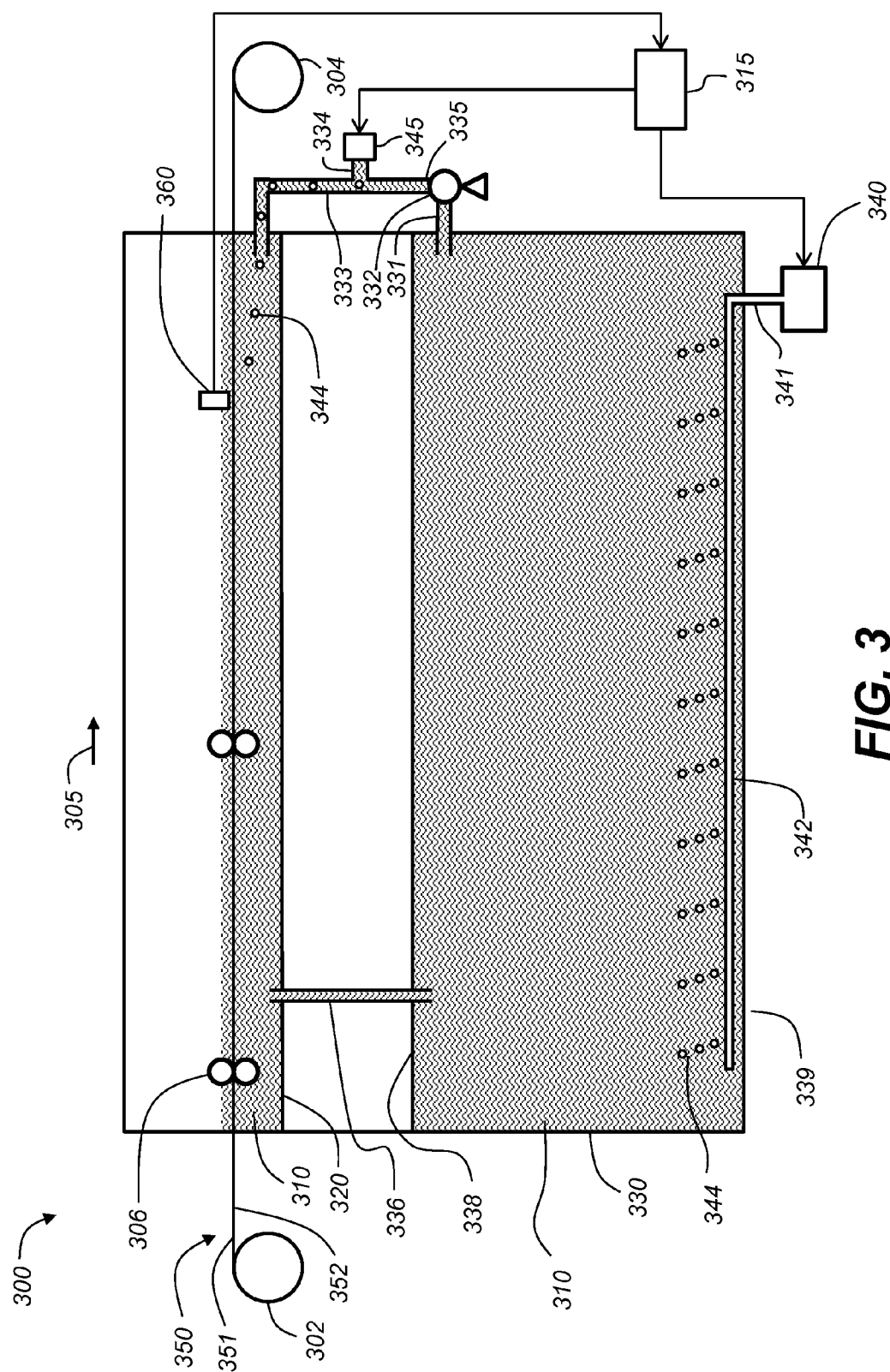
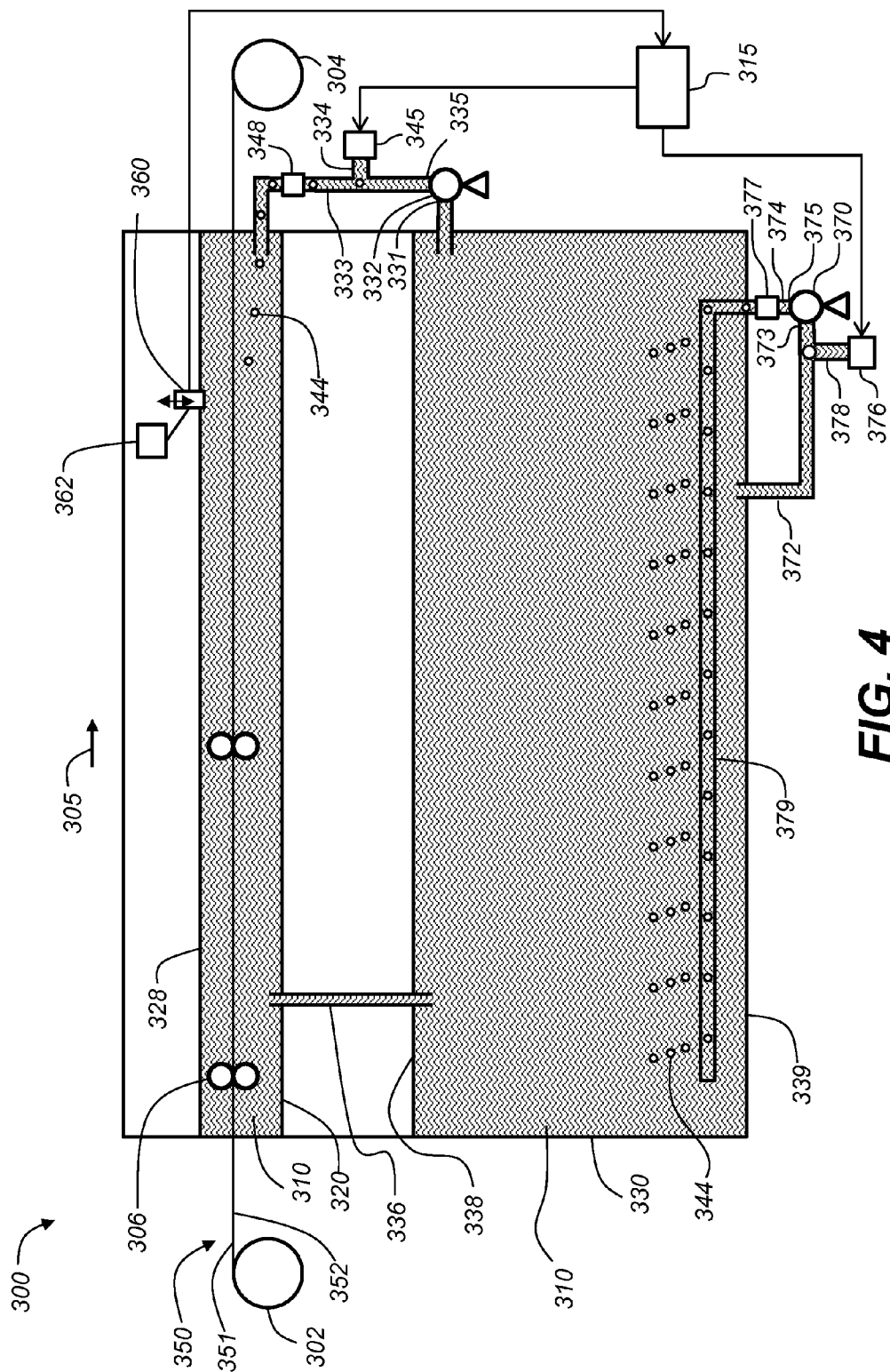


FIG. 3



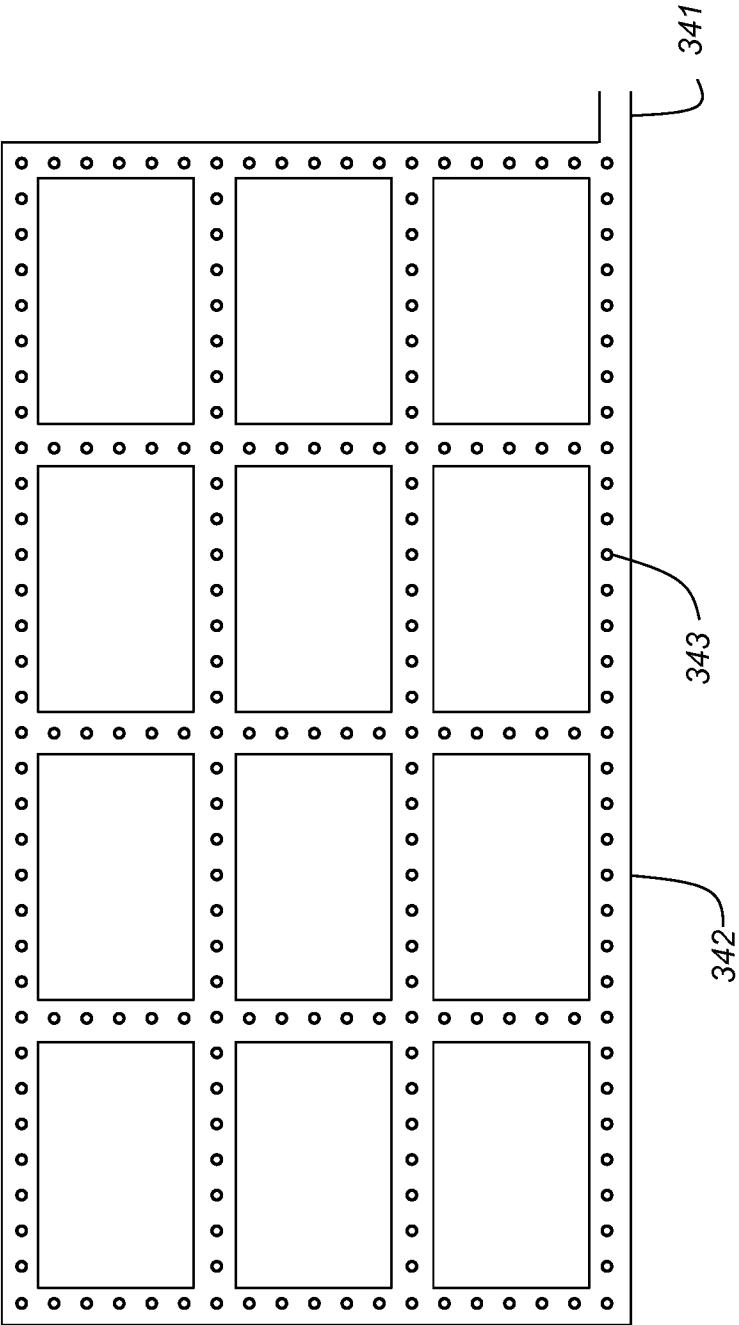


FIG. 5A

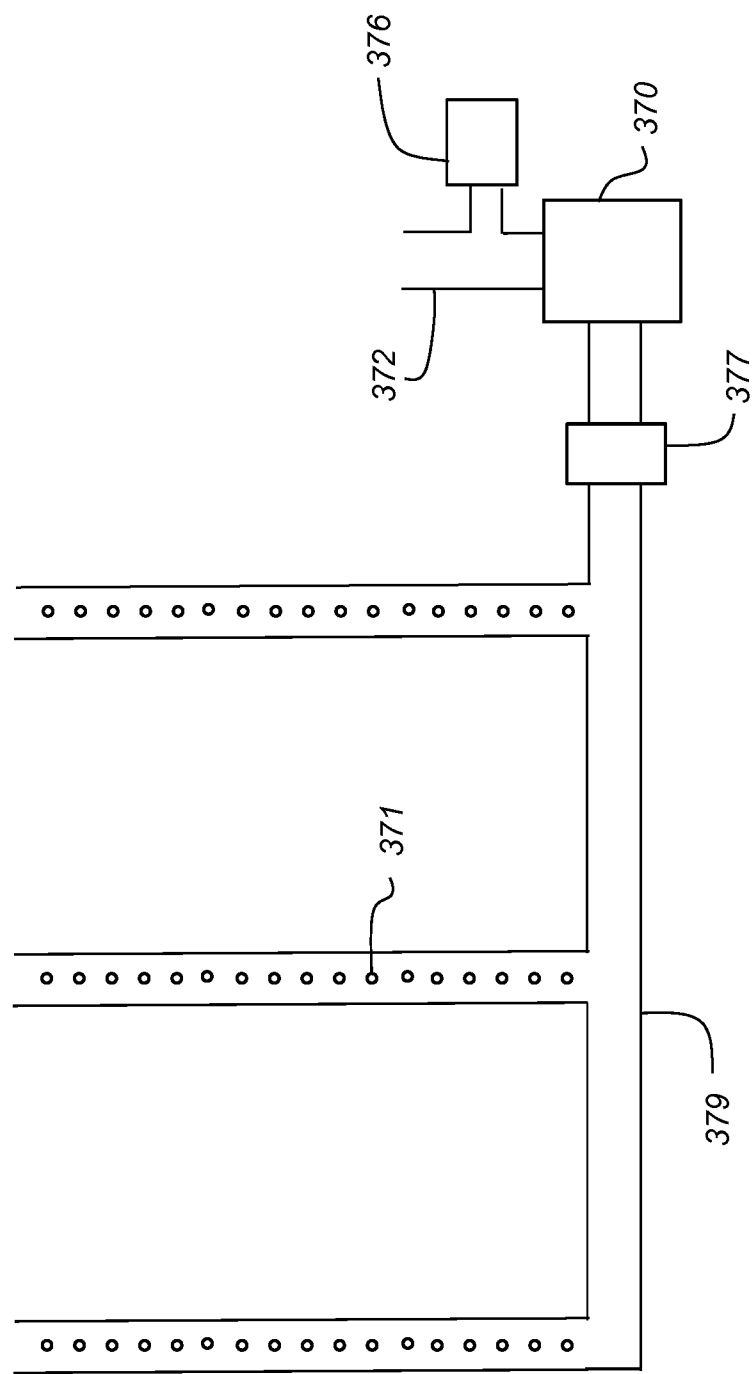


FIG. 5B

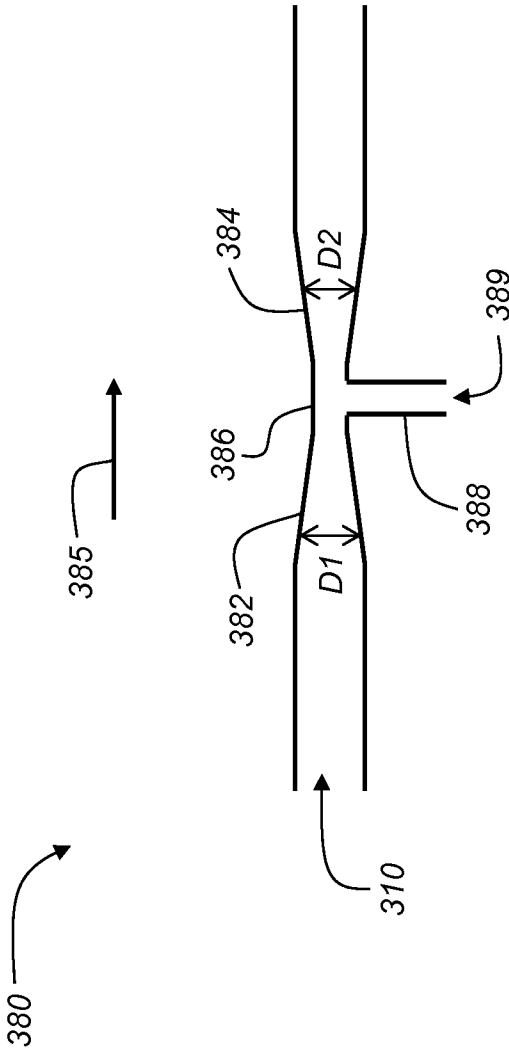


FIG. 6

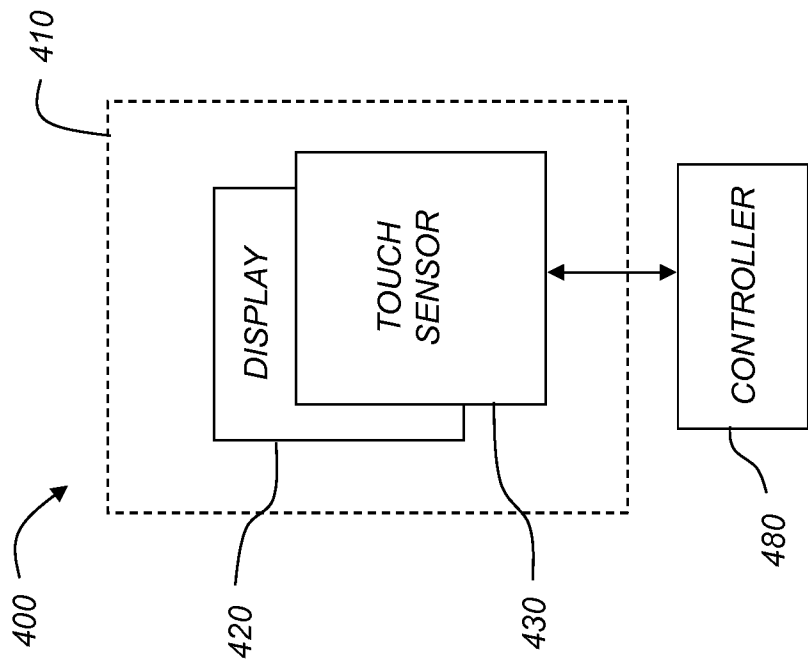


FIG. 7

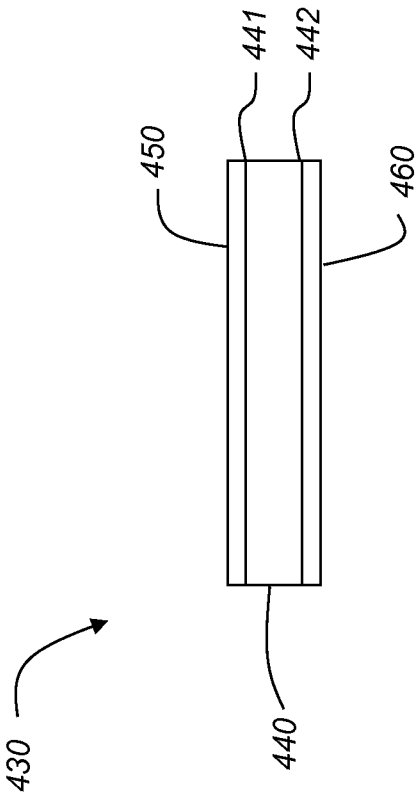


FIG. 8

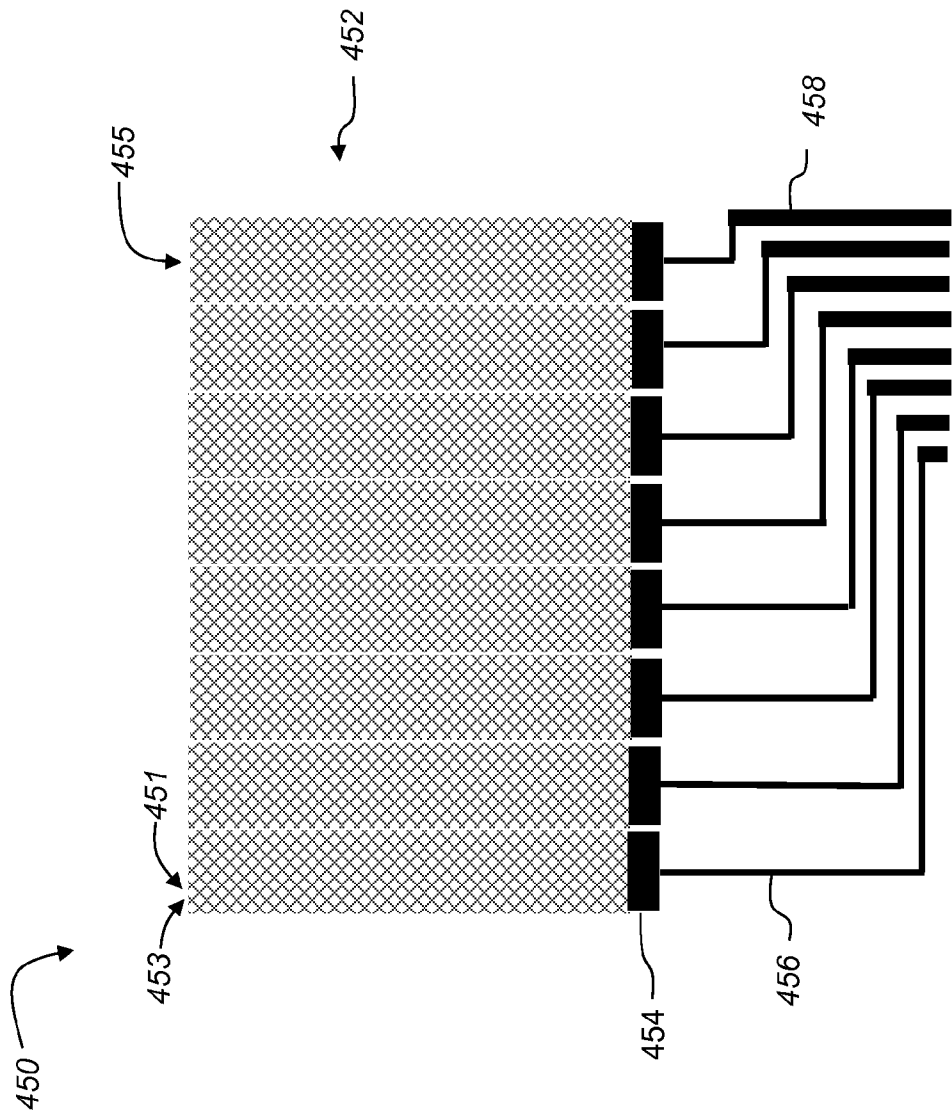


FIG. 9

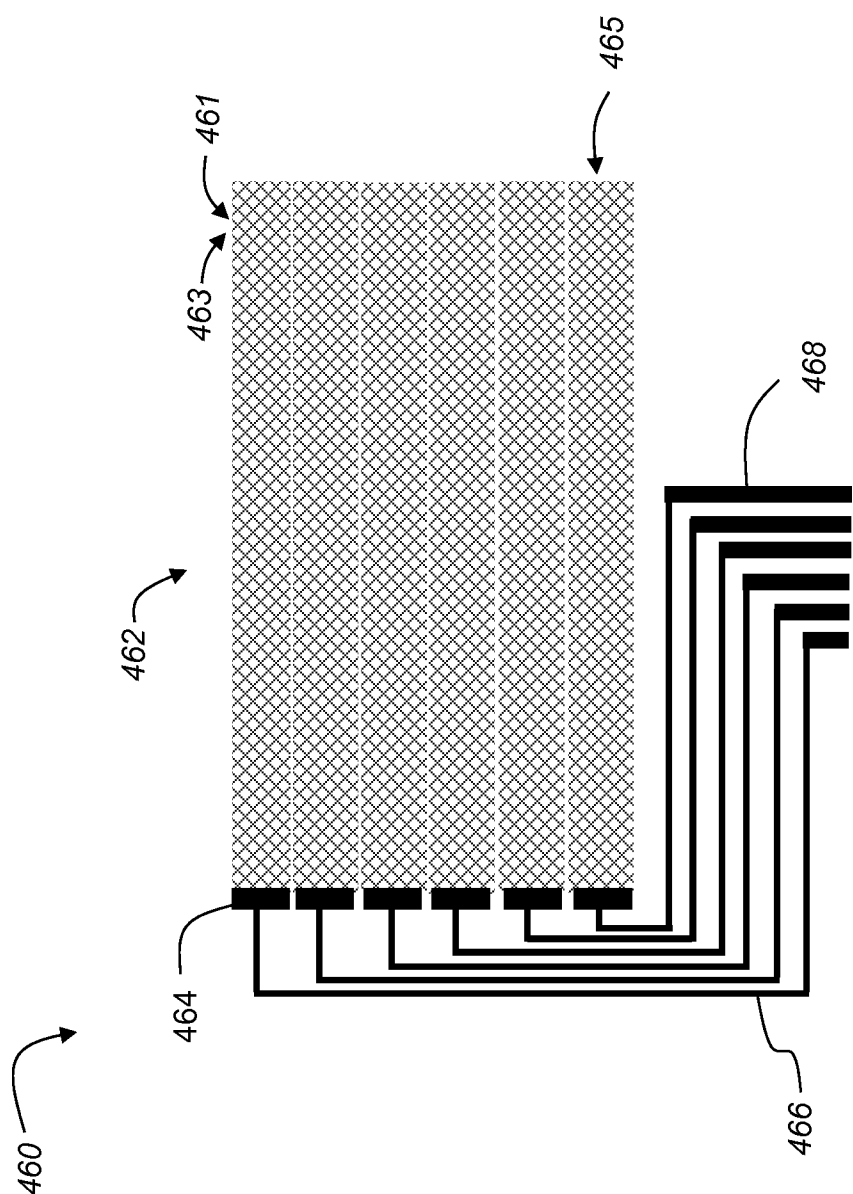


FIG. 10

ROLL-TO-ROLL ELECTROLESS PLATING SYSTEM WITH MICRO-BUBBLE INJECTOR

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Reference is made to commonly-assigned, co-pending U.S. patent application Ser. No. _____ (Docket K001833), entitled “Roll-to-roll electroless plating system with low dissolved oxygen content” by G. Wainwright et al.; and to commonly-assigned, co-pending U.S. patent application Ser. No. _____ (Docket K001834), entitled “Method for roll-to-roll electroless plating with low dissolved oxygen content” by G. Wainwright et al., each of which is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] This invention pertains to the field of roll-to-roll electroless plating, and more particularly to a system and method for providing low dissolved oxygen content in the plating solution.

BACKGROUND OF THE INVENTION

[0003] Electroless plating, also known as chemical or autocatalytic 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.

[0004] 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 may 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.

[0005] Projected capacitive touch technology is a variant of capacitive touch 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 capaci-

tance 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.

[0006] WO 2013/063188 by Petcavich et al. 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 subsequent electroless plating. 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.

[0007] 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.

[0008] 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.

[0009] 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.

[0010] 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.

[0011] Roll-to-roll electroless plating systems are commercially available from Chemcut Corporation, for example. However, commercially available roll-to-roll electroless plating systems are adapted to be used with plating solutions that include a relatively high amount of dissolved oxygen, for example greater than three parts per million. Such plating solutions can work well for plating copper in the context of printed circuit board manufacture where the minimum line width is on the order of 100 microns. However, it has been found that such oxygen-rich plating solutions do not provide uniform metallization at high yield on features having line widths of 10 microns or less.

[0012] Dissolved oxygen content of an electroless plating solution influences the rate and quality of the plating. As indicated in U.S. Pat. No. 4,616,596 Helber Jr. et al., entitled "Electroless plating apparatus," U.S. Pat. No. 4,684,545 to Fey et al., entitled "Electroless plating with bi-level control of dissolved oxygen," and U.S. Patent Application Publication No. 2011/0214608 to Ivanov et al., entitled "Electroless Plating System," increased oxygen content tends to stabilize plating and decrease the plating rate. Decreased oxygen content tends to increase plating activity.

[0013] It has been found that a copper electroless plating solution made by Enthone is well-suited to provide high quality plating on features having minimum line widths of 10 microns or less in a low dissolved oxygen content tank plating system, but not in a commercially available roll-to-roll electroless plating system. What is needed is a roll-to-roll plating system and method that can provide and maintain low dissolved oxygen content in the plating solution.

SUMMARY OF THE INVENTION

[0014] The present invention represents a roll-to-roll electroless plating system, comprising:

[0015] a reservoir containing plating solution;

[0016] a web advance system for advancing a web of media from an input roll through the plating solution in the reservoir 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 reservoir; and

[0017] a distribution system for injecting an inert gas into the plating solution, wherein the distribution system includes an injector for injecting the inert gas into the plating solution, wherein the injector includes:

[0018] a converging tube segment;

[0019] a diverging tube segment downstream of the converging tube segment;

[0020] a throat formed at a junction of the converging tube segment and the diverging tube segment; and

[0021] an inlet for the inert gas in proximity to the throat.

[0022] This invention has the advantage that the inert gas for reducing the amount of dissolved oxygen can be injected from a low pressure gas source into the plating solution downstream of a pump.

[0023] It has the additional advantage that the injector can form micro-bubbles of the inert gas which are more efficient at reducing the dissolved oxygen content in the plating solution.

[0024] It the further advantage that the injection of the inert gas reduces the amount of dissolved oxygen in the plating solution to provide dissolved oxygen levels appropriate for

use with plating solutions whose performance degrades at higher levels of dissolved oxygen.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] FIG. 1 is a schematic side view of a flexographic printing system for roll-to-roll printing on both sides of a substrate;

[0026] FIG. 2 is a schematic side view of a prior art roll-to-roll electroless plating system;

[0027] FIG. 3 is a schematic side view of a roll-to-roll electroless plating system according to an embodiment of the invention;

[0028] FIG. 4 is a schematic side view of a roll-to-roll electroless plating system according to another embodiment of the invention;

[0029] FIG. 5A is a top view of an exemplary embodiment of a plumbing assembly for distributing inert gas bubbles into the plating solution;

[0030] FIG. 5B is a top view of another exemplary embodiment of a plumbing assembly for distributing inert gas bubbles into the plating solution;

[0031] FIG. 6 is a side view of an injector for injecting inert gas at a localized low pressure region;

[0032] FIG. 7 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;

[0033] FIG. 8 is a side view of the touch sensor of FIG. 7;

[0034] FIG. 9 is a top view of a conductive pattern printed on a first side of the touch sensor of FIG. 8; and

[0035] FIG. 10 is a top view of a conductive pattern printed on a second side of the touch sensor of FIG. 8.

[0036] 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

[0037] 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.

[0038] 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.

[0039] 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.

[0040] 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.

[0041] As described herein, the example embodiments of the present invention provide a roll-to-roll electroless plating system and methods for providing and maintaining low dissolved oxygen content in the plating solution. 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.

[0042] FIG. 1 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.

[0043] 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. 1). 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.

[0044] 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. 1, 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.

[0045] 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.

[0046] FIG. 2 is a schematic side view of a prior art roll-to-roll electroless plating system 200, similar to a configuration available from Chemcut Corporation, for use with a plating solution 210. The roll-to-roll electroless plating system 200 performs well with plating solutions 210 that are formulated for optimized plating with relatively high dissolved oxygen content (e.g., greater than 3 parts per million). Substrate 250 is fed as a web of media from supply roll 202 to take-up roll 204. Drive rollers 206 advance the web in a web advance direction 205 from the supply roll 202 through a reservoir of the plating solution 210 to the take-up roll 204. In the configuration shown in FIG. 2, a sump 230 contains a large volume of the plating solution 210, and a pan 220 positioned above the sump contains a smaller volume of the plating solution 210.

[0047] As the substrate 250 is advanced through the plating solution 210 in the pan 220, a metallic plating substance such as copper, silver, 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 substrate 250. As a result, the concentration of the metal in the plating solution 210 in the pan 220 decreases and the plating solution 210 needs to be refreshed. To refresh the plating solution 210, it is recirculated between the sump 230 and the pan 220. A lower lift pump 232 moves plating solution 210 from the sump 230 through a pipe 233 to a lower flood bar 222 for distribution into the pan 220 below the substrate 250. Likewise, an upper lift pump 234 moves plating solution 210 from the sump 230 through a pipe 235 to an upper flood bar 224 for distribution into the pan 220 above the substrate 250. Excess plating solution 210 waterfalls back into the sump 230 at freefall return 236. Occasionally the plating solution 210 is chemically analyzed, for example by titration, and fresh plating solution 210, or components of the plating solution 210, are added to the sump 230 as needed. Air inlet tubes 240 are provided to provide additional oxygen to the plating solution 210 in sump 230 as needed.

[0048] Although the prior art roll-to-roll electroless plating system 200 shown in FIG. 2 works well for plating solutions 210 that are designed to plate at relatively high levels of dissolved oxygen, for example greater than 3 parts per million, it has been found that it does not work well for plating solutions 210 that are designed to plate at a lower level of dissolved oxygen, for example between about 0.5 parts per million and about 2 parts per million. Not adding air through the air inlet tubes 240 is an obvious measure for reducing the dissolved oxygen content in the plating solution 210. However, in order to control the dissolved oxygen content at the desired low level, it is necessary to make significant modifications to the roll-to-roll electroless plating system 200.

[0049] FIG. 3 is a schematic side view of an improved roll-to-roll electroless plating system 300 which is useful for plating solutions 310 having a low level of dissolved oxygen content. As in the prior art electroless plating system 200, a substrate 350 is fed as a web of media from a supply roll 302 to a take-up roll 304. Drive rollers 306 advance the web of substrate 350 along a web advance direction 305 from the supply roll 302 through a reservoir of plating solution 310 to the take-up roll 304. A sump 330 contains a large volume of the plating solution 310 and a pan 320 positioned above the

sump contains a smaller volume of the plating solution 310. The term “reservoir” can be used to refer to either the sump 330 or the pan 320.

[0050] As the substrate 350 is advanced through the plating solution 310 in pan 320, a metallic plating substance such as copper, silver, nickel or palladium is electrolessly plated from the plating solution 310 onto predetermined locations on one or both of a first surface 351 and a second surface 352 of the substrate 350. The predetermined locations can be provided, for example, by the prior printing of a catalytic ink.

[0051] A number of modifications have been made relative to the prior art similar to a configuration available from roll-to-roll electroless plating system 200 of FIG. 2 to control the amount of dissolved oxygen in the plating solution within a lower range of about 0.5 to about 2 parts per million. The modifications include measures to a) reduce the amount of turbulence in the plating solution 310 in portions of the roll-to-roll electroless plating system 300 that are exposed to air, b) reduce the exposure of the plating solution 310 to ambient air, c) displace dissolved oxygen from the plating solution 310, and d) sense the amount of dissolved oxygen in the plating solution 310.

[0052] Modifications for reducing turbulence in the roll-to-roll electroless plating system 300 of FIG. 3 relative to the prior art roll-to-roll electroless plating system 200 of FIG. 2 include replacing the freefall return 236 (FIG. 2) with a more controlled flow of the plating solution 310 through a drain pipe 336; eliminating the lower flood bar 222 and the upper flood bar 224 (FIG. 2); and removing the upper lift pump 234 and its associated plumbing. Instead, in roll-to-roll electroless plating system 300, there is only a single pan-replenishing pump 332 that moves plating solution 310 from the sump 330 to the pan 320 through a pipe 333 connected to an outlet 335 of the pan-replenishing pump 332. Plating solution 310 enters the pan-replenishing pump 332 from sump 330 via an inlet 331.

[0053] In addition to reducing splashing and other forms of turbulence, drain pipe 336 also reduces the exposure of plating solution 310 to ambient air. The top of drain pipe 336 is within the plating solution 310 in pan 320, and the bottom of drain pipe 336 is within the plating solution 310 in sump 330. Other measures for reducing the exposure of plating solution 310 to ambient air include providing a sump cover 338 and optionally providing a pan cover 328 (see FIG. 4).

[0054] Preferred embodiments of the invention also include modifications that provide for the displacement of dissolved oxygen from the plating solution 310. This is done by injecting an inert gas into the plating solution 310 via a distribution system. As used herein, the term inert gas refers to a gas that does not take part in the chemical reactions necessary for electroless plating. Nitrogen is an example of such an inert gas. Another example of an inert gas would be argon. In various embodiments, the inert gas can also be injected into one or both of the sump 330 and pan 320. FIG. 3 shows inert gas being injected into the pan 320 from an inert gas source 345. In the illustrated embodiment, the inert gas from the inert gas source 345 is inserted into pipe 333 at through tee 334, forming bubbles 344 which are carried into the pan 320.

[0055] FIG. 3 also shows bubbles 344 of inert gas being injected into the sump 330 from inert gas source 340. As the inert gas is dissolved in the plating solution 310, the amount of dissolved oxygen decreases. To facilitate dissolution of the inert gas, it is advantageous to inject the inert gas as micro-

bubbles and to distribute the inert gas in such a way as to promote longer paths through the plating solution 310 before exiting. In the embodiment of FIG. 3, the bubbles 344 are injected through a plumbing assembly 342 located near a bottom 339 of sump 330 so that the injected bubbles 344 will rise through nearly the entire height of the plating solution 310. The inert gas enters the plumbing assembly 342 from the inert gas source 340 through an inert gas inlet 341. As shown in the top view of FIG. 5A, in an exemplary embodiment the plumbing assembly 342 has a network of distributed orifices 343, so that the inert gas bubbles 344 enter the plating solution 310 more uniformly, thereby facilitating dissolution by avoiding forming a few regions of inert-gas-saturated plating solution 310.

[0056] Within the context of the present invention, micro-bubbles are defined as bubbles having a diameter between about one micron (one thousandth of a millimeter) and one millimeter. Since the ratio of surface area to volume of a sphere is inversely dependent upon diameter, micro-bubbles have a larger surface area to volume ratio than larger bubbles, thereby facilitating efficient dissolution into the plating solution 310. In addition, micro-bubbles tend to stay suspended longer in the plating solution 310 rather than rising and bursting rapidly. As described below, there are a variety of ways to inject the inert gas into the plating solution 310 in the form of micro-bubbles.

[0057] It is also advantageous to control the amount of flow of inert gas into the plating solution 310 according to a measured amount of dissolved oxygen in the plating solution 310. An oxygen sensor 360 can be immersed into, or periodically dipped into, the plating solution 310 to measure the dissolved oxygen content. The data from the oxygen sensor 360 can be provided to a controller 315 to control the rate of flow of inert gas injected into plating solution 310 from inert gas source 340 or inert gas source 345, for example by controlling flow rate through a needle valve (not shown).

[0058] FIG. 4 shows a schematic side view of an alternate embodiment of a roll-to-roll electroless plating system 300 that injects micro-bubbles of inert gas into the sump 330 by means of a recirculation system including a recirculation pump 370 having an inlet 373 and an outlet 375; an inlet line 372 for moving plating solution 310 from the sump 330 to the pump inlet 373; and an outlet line 374 for returning plating solution 310 from the pump outlet 375 to the sump 330. In the example shown in FIG. 4, inert gas is injected into the low pressure inlet 373 of the recirculation pump 370 from an inert gas source 376 connected to inlet 373 by tee 378. Mechanical action within recirculation pump 370 tends to break inert gas bubbles into micro-bubbles, which then flow together with plating solution 310 from the pump outlet 375 into the sump 330 through a plumbing assembly 342 located near bottom 339 of sump 330 providing the bubbles 344. Furthermore, a filter 377 can be disposed in the outlet line 374 for removing particulates so that they do not re-enter the sump 330. A second function of filter 377, which may have a pore size on the order of one micron, can optionally be used to break up bubbles of inert gas into micro-bubbles. Thus, inert gas is injected into the plating solution 310 outside the sump 330 to provide an inert-gas-rich plating solution 310, and the inert-gas-rich plating solution 310 is delivered into the sump 330.

[0059] FIG. 5B shows a top view of an exemplary embodiment of the plumbing assembly 379, where the inert gas is injected from the inert gas source 376 into the inlet line 372 to the recirculation pump 370. The inert gas bubbles pass

through a filter 377 before entering plumbing assembly 379. The bubbles of inert gas have a long flow path within plumbing assembly 379 before exiting at distributed orifices 371, thereby aiding dissolution of the inert gas into the plating solution 310 (FIG. 4) within the plumbing assembly 379.

[0060] An advantage of injecting inert gas on the low pressure inlet side of a pump is that the inert gas source 376 can be a low pressure source for improved flow control. However, a potential disadvantage of injecting inert gas into a pump inlet is cavitation damage within the pump. FIG. 4 also shows inert gas flowing from inert gas source 345 through a tee 334 into pipe 333 downstream of the outlet 335 of pan-replenishing pump 332. Thus, inert gas is injected into the plating solution 310 outside the pan 320 to provide an inert-gas-rich plating solution 310, and the inert-gas-rich plating solution 310 is delivered into the pan 320 through the pipe 333. A filter 348 can be used for further reducing the size of bubbles.

[0061] In some embodiments, a static mixer (not shown) having a tortuous flow path around baffles can be inserted in-line with pipe 333 to facilitate dissolution of the inert gas micro-bubbles within the plating solution 310 being returned to pan 320 through pipe 333.

[0062] Although FIG. 4 shows inert gas provided upstream of the inlet 373 of recirculation pump 370, and shows inert gas provided downstream of the outlet 335 of pan-replenishing pump 332, alternatively inert gas could be provided downstream of outlet 375 of recirculation pump 370 or upstream of inlet 331 of pan-replenishing pump 332.

[0063] For configurations where the inert gas is provided downstream of the outlet of a pump (i.e., on the high pressure side of the pump), it is advantageous to provide a local low pressure region where the inert gas can be injected. For example, in FIG. 4, it can be useful to provide a local low pressure region where the inert gas is injected downstream of the outlet 335 of the pan-replenishing pump 332. FIG. 6 is a side view of an injector 380 (sometimes called a Venturi injector) for providing a local low pressure region at a gas injection site. The injector 380 can be used at the position of the tee 334 in FIG. 4. Injector 380 includes a throat 386; converging tube segment 382 upstream of the throat 386 having a diameter D1 that decreases from an upstream portion to a downstream portion; and a diverging tube segment 384 downstream of the throat 386 having a diameter D2 that increases from an upstream portion to a downstream portion. The throat 386 is formed by the junction of the converging tube segment 382 and the diverging tube segment 384. The plating solution 310 flows through the injector 380 from upstream to downstream in flow direction 385. Due to the Venturi effect, a localized low pressure region is formed at the throat 386. By providing an inlet 388 for inert gas 389 in proximity to the throat 386, a low pressure source of inert gas, such as inert gas sources 340, 345 (FIG. 4) can be used. In some operating conditions it has been found that micro-bubbles tend to be formed when the inert gas is injected using injector 380, thereby providing an additional advantage for the use of this device. In some embodiments, an injector 380 can be also be used to inject inert gas downstream of the outlet 375 of the recirculation pump 370 (FIG. 4).

[0064] Having described exemplary embodiments of the roll-to-roll electroless plating system 300, a context has been provided for describing further details of methods for controlling the dissolved oxygen content to be at its desired low range (e.g., in the range of about 0.5 to about 2 parts per million). As described above, an amount of dissolved oxygen

in the plating solution 310 is measured using oxygen sensor 360. The measured amount of dissolved oxygen is compared to a target range of dissolved oxygen. If the measured amount of dissolved oxygen is greater than the target range of dissolved oxygen, then the rate of injecting the inert gas is increased, for example by further opening a needle valve through which the inert gas flows to increase the flow rate. If the measured amount of dissolved oxygen is less than the target range of dissolved oxygen, then the rate of injecting the inert gas is decreased, for example by further closing a needle valve through which the inert gas flows to decrease the flow rate.

[0065] In some embodiments, the measuring of the amount of dissolved oxygen can be repeated at specified time intervals, for example once every five minutes or once every hour. During start-up of the electroless plating process, prior to injecting inert gas, the plating solution 310 tends to be somewhat oxygen rich. Therefore, it can be advantageous to measure the dissolved oxygen content at a relatively high repetition frequency (e.g., once every five minutes) during a start-up phase, and then to measure the dissolved oxygen content at a lower repetition frequency (e.g., once per thirty minutes) after the system has stabilized and the dissolved oxygen content has reached the target range.

[0066] In some embodiments, measurement of dissolved oxygen content can also be initiated by the controller 315 if it detects that an environmental condition has changed. For example, a measurement can be initiated if the controller 315 senses that the temperature of the plating solution 310 has changed by more than a predetermined threshold, as gas solubility is a function of temperature.

[0067] In some embodiments, measurement of dissolved oxygen content can also be initiated when a system operating condition changes. For example, a measurement can be initiated if the pan cover 328 is removed for service, thereby exposing the surface of the plating solution 310 to the air. Likewise, a measurement can be initiated when fresh plating solution 310, or components of the plating solution 310, are added to the sump 330.

[0068] In some embodiments, measurement of dissolved oxygen content can also be initiated when an indication is detected that the system may not be performing in the intended manner. For example, a measurement can be initiated if it is observed that elements of the plating solution 310 are plating onto extraneous surfaces other than the intended features on the substrate 250.

[0069] In some embodiments, a user interface can be provided to enable the measurement of dissolved oxygen to be manually initiated by an operator. For example, if it is observed that the system performance has been degraded.

[0070] For embodiments where the inert gas is injected into the plating solution 310 for delivery into both the sump 330 and the pan 320, the rates of injection can be independently controlled by controller 315. For example, the injection of the inert gas into the plating solution 310 for delivery into the sump 330 can be done at a first rate, and the injection of inert gas into the plating solution 310 for delivery into the pan 320 can be done at a second rate that is different from the first rate.

[0071] FIG. 3 shows the oxygen sensor 360 submerged within the plating solution 310 in pan 320. In some embodiments, if the oxygen sensor 360 is kept within the plating solution 310, metal can deposit on it, thereby affecting its performance. FIG. 4 shows an embodiment where the oxygen sensor 360 is configured to be repositionable. Under control

of controller 315, a motor 362 controllably lowers the oxygen sensor 360 to dip it into the plating solution 310 (e.g., through an opening in the pan cover 328) in order to measure dissolved oxygen content. The controller 315 can then control the motor 362 to raise the oxygen sensor 360 to remove it from the plating solution after the measurement is made. Data indicating the measured amount of dissolved oxygen can be sent to controller 315 either before or after the oxygen sensor 360 is removed from the plating solution 310.

[0072] FIG. 7 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 and plated using an embodiment of roll-to-roll electroless plating system 300 with low dissolved oxygen content described above.

[0073] FIG. 8 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. 1), 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.

[0074] FIG. 9 shows an example of a conductive pattern 450 that can be printed on first side 441 (FIG. 8) of substrate 440 (FIG. 8) using one or more print modules such as print modules 120 and 140 of flexographic printing system (FIG. 1), followed by plating using an embodiment of roll-to-roll electroless plating system 300 (FIGS. 3 and 4). 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. 7). 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. 1) configured similarly to print modules 120 and 140.

[0075] FIG. 10 shows an example of a conductive pattern 460 that can be printed on second side 442 (FIG. 8) of substrate 440 (FIG. 8) using one or more print modules such as print modules 110 and 130 of flexographic printing system (FIG. 1), followed by plating using an embodiment of roll-to-roll electroless plating system 300 (FIGS. 3 and 4). 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 con-

nect the channel pads 464 to the connector pads 468 that are connected to controller 480 (FIG. 7). 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. 1) configured similarly to print modules 110 and 130.

[0076] 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. 1 followed by plating using an embodiment of roll-to-roll electroless plating system 300 (FIGS. 3 and 4).

[0077] With reference to FIGS. 7-10, 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.

[0078] 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

[0079]	100 flexographic printing system
[0080]	102 supply roll
[0081]	104 take-up roll
[0082]	105 roll-to-roll direction
[0083]	106 roller
[0084]	107 roller
[0085]	110 print module
[0086]	111 plate cylinder
[0087]	112 flexographic printing plate
[0088]	113 raised features
[0089]	114 impression cylinder
[0090]	115 anilox roller
[0091]	116 UV curing station
[0092]	120 print module
[0093]	121 plate cylinder
[0094]	122 flexographic printing plate
[0095]	124 impression cylinder
[0096]	125 anilox roller
[0097]	126 UV curing station
[0098]	130 print module
[0099]	131 plate cylinder
[0100]	132 flexographic printing plate
[0101]	134 impression cylinder
[0102]	135 anilox roller
[0103]	136 UV curing station
[0104]	140 print module
[0105]	141 plate cylinder
[0106]	142 flexographic printing plate
[0107]	144 impression cylinder

[0108] 145 anilox roller
 [0109] 146 UV curing station
 [0110] 150 substrate
 [0111] 151 first side
 [0112] 152 second side
 [0113] 200 roll-to-roll electroless plating system
 [0114] 202 supply roll
 [0115] 204 take-up roll
 [0116] 205 web advance direction
 [0117] 206 drive roller
 [0118] 210 plating solution
 [0119] 220 pan
 [0120] 222 lower flood bar
 [0121] 224 upper flood bar
 [0122] 230 sump
 [0123] 232 lower lift pump
 [0124] 233 pipe
 [0125] 234 upper lift pump
 [0126] 235 pipe
 [0127] 236 freefall return
 [0128] 240 air inlet tube
 [0129] 250 substrate
 [0130] 251 first surface
 [0131] 252 second surface
 [0132] 300 roll-to-roll electroless plating system
 [0133] 302 supply roll
 [0134] 304 take-up roll
 [0135] 305 web advance direction
 [0136] 306 drive roller
 [0137] 310 plating solution
 [0138] 315 controller
 [0139] 320 pan
 [0140] 328 pan cover
 [0141] 330 sump
 [0142] 331 inlet
 [0143] 332 pan-replenishing pump
 [0144] 333 pipe
 [0145] 334 tee
 [0146] 335 outlet
 [0147] 336 drain pipe
 [0148] 338 sump cover
 [0149] 339 bottom
 [0150] 340 inert gas source
 [0151] 341 inert gas inlet
 [0152] 342 plumbing assembly
 [0153] 343 orifices
 [0154] 344 bubbles
 [0155] 345 inert gas source
 [0156] 348 filter
 [0157] 350 substrate
 [0158] 351 first surface
 [0159] 352 second surface
 [0160] 360 oxygen sensor
 [0161] 362 motor
 [0162] 370 recirculation pump
 [0163] 371 orifices
 [0164] 372 inlet line
 [0165] 373 inlet
 [0166] 374 outlet line
 [0167] 375 outlet
 [0168] 376 inert gas source
 [0169] 377 filter
 [0170] 378 tee
 [0171] 379 plumbing assembly

[0172] 380 injector
 [0173] 382 converging tube segment
 [0174] 384 diverging tube segment
 [0175] 385 flow direction
 [0176] 386 throat
 [0177] 388 inlet
 [0178] 389 inert gas
 [0179] 400 apparatus
 [0180] 410 touch screen
 [0181] 420 display device
 [0182] 430 touch sensor
 [0183] 440 transparent substrate
 [0184] 441 first side
 [0185] 442 second side
 [0186] 450 conductive pattern
 [0187] 451 fine lines
 [0188] 452 grid
 [0189] 453 fine lines
 [0190] 454 channel pads
 [0191] 455 grid column
 [0192] 456 interconnect lines
 [0193] 458 connector pads
 [0194] 460 conductive pattern
 [0195] 461 fine lines
 [0196] 462 grid
 [0197] 463 fine lines
 [0198] 464 channel pads
 [0199] 465 grid row
 [0200] 466 interconnect lines
 [0201] 468 connector pads
 [0202] 480 controller
 [0203] D1 diameter
 [0204] D2 diameter

1. A roll-to-roll electroless plating system, comprising:
 - a reservoir containing plating solution;
 - a web advance system for advancing a web of media from an input roll through the plating solution in the reservoir 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 reservoir; and
 - a distribution system for injecting an inert gas into the plating solution, wherein the distribution system includes an injector for injecting the inert gas into the plating solution, wherein the injector includes:
 - a converging tube segment;
 - a diverging tube segment downstream of the converging tube segment;
 - a throat formed at a junction of the converging tube segment and the diverging tube segment; and
 - an inlet for the inert gas in proximity to the throat.
2. The roll-to-roll electroless plating system of claim 1, wherein diameters of the converging and diverging tube segments increase with distance from the throat.
3. The roll-to-roll electroless plating system of claim 1, wherein the injector is located downstream of a pump which pumps the plating solution through the injector.
4. The roll-to-roll electroless plating system of claim 1, wherein the injector injects micro-bubbles of the inert gas into the plating solution, wherein the micro-bubbles have a diameter between about one micron and one millimeter.
5. The roll-to-roll electroless plating system of claim 1, wherein the plating substance is copper, silver, nickel or palladium.

6. The roll-to-roll electroless plating system of claim 1, wherein the inert gas is nitrogen or argon.

7. The roll-to-roll electroless plating system of claim 1, further including a recirculation system including:

- a recirculation pump including an inlet and an outlet;
- an inlet line for moving plating solution from the reservoir to the pump inlet; and
- an outlet line for returning plating solution from the pump outlet to the reservoir.

8. The roll-to-roll electroless plating system of claim 7, wherein the distribution system is configured to inject the inert gas into the outlet line.

9. The roll-to-roll electroless plating system of claim 7, further comprising a filter in the outlet line.

10. The roll-to-roll electroless plating system of claim 1, wherein the distribution system includes a plumbing assembly having a plurality of distributed orifices for providing bubbles of inert gas into the reservoir.

11. The roll-to-roll electroless plating system of claim 10, wherein the plumbing assembly is disposed proximate to a bottom of the sump.

12. The roll-to-roll electroless plating system of claim 1, further comprising an oxygen sensor.

13. The roll-to-roll electroless plating system of claim 12, further comprising a controller, wherein the controller is configured to receive data from the oxygen sensor and to control a rate of injection of the inert gas into the plating solution in response to the data received from the oxygen sensor.

14. The roll-to-roll electroless plating system of claim 13, wherein a dissolved oxygen content of the plating solution is controlled to be between 0.5 and 2 parts per million.

15. The roll-to-roll electroless plating system of claim 1, wherein the reservoir further includes a reservoir cover.

16. The roll-to-roll electroless plating system of claim 1, wherein the distribution system further includes a static mixer.

17. The roll-to-roll electroless plating system of claim 1, wherein the predetermined locations include features printed onto the web of media with ink including a catalyst for plating.

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

19. The article of claim 18, wherein at least some of the features have widths between 2 microns and 10 microns.

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