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(54) **MANIFOLD COMPATIBLE ELECTROLYTIC CELL (EO CELL) WITH COPLANAR FLUIDIC AND ELECTRICAL CONNECTION SCHEME**

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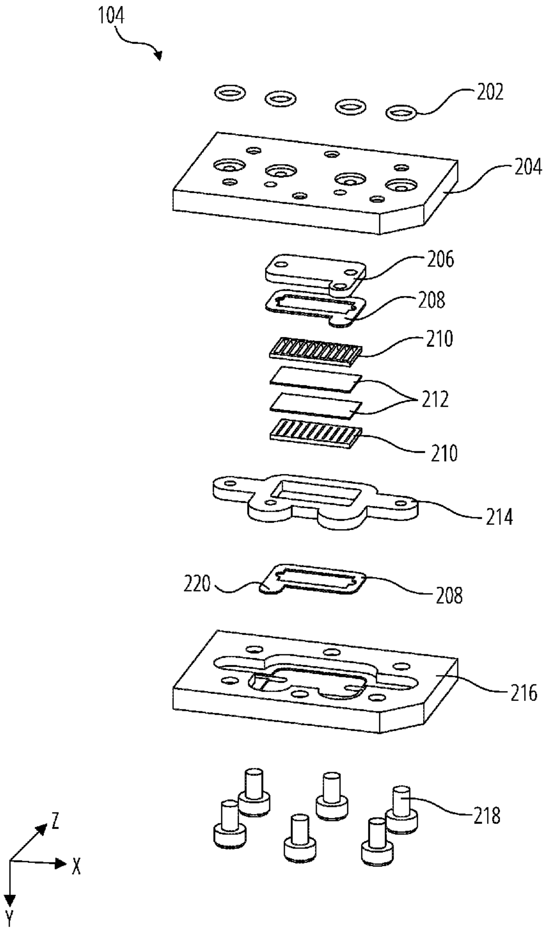
(57) **ABSTRACT**

An electrolytic ozone cell that a housing that includes an interfacial seal, a top plate, and bottom plate. The electrolytic ozone cell also includes an internal compartment that having a pair of contact plates, and a tolerance compressor. The tolerance compressor compresses an electrode-membrane-electrode stack that is disposed between the pair of contact plates and the tolerance compressor alters its shape in order to maintain compressive forces on the electrode-membrane-electrode stack.



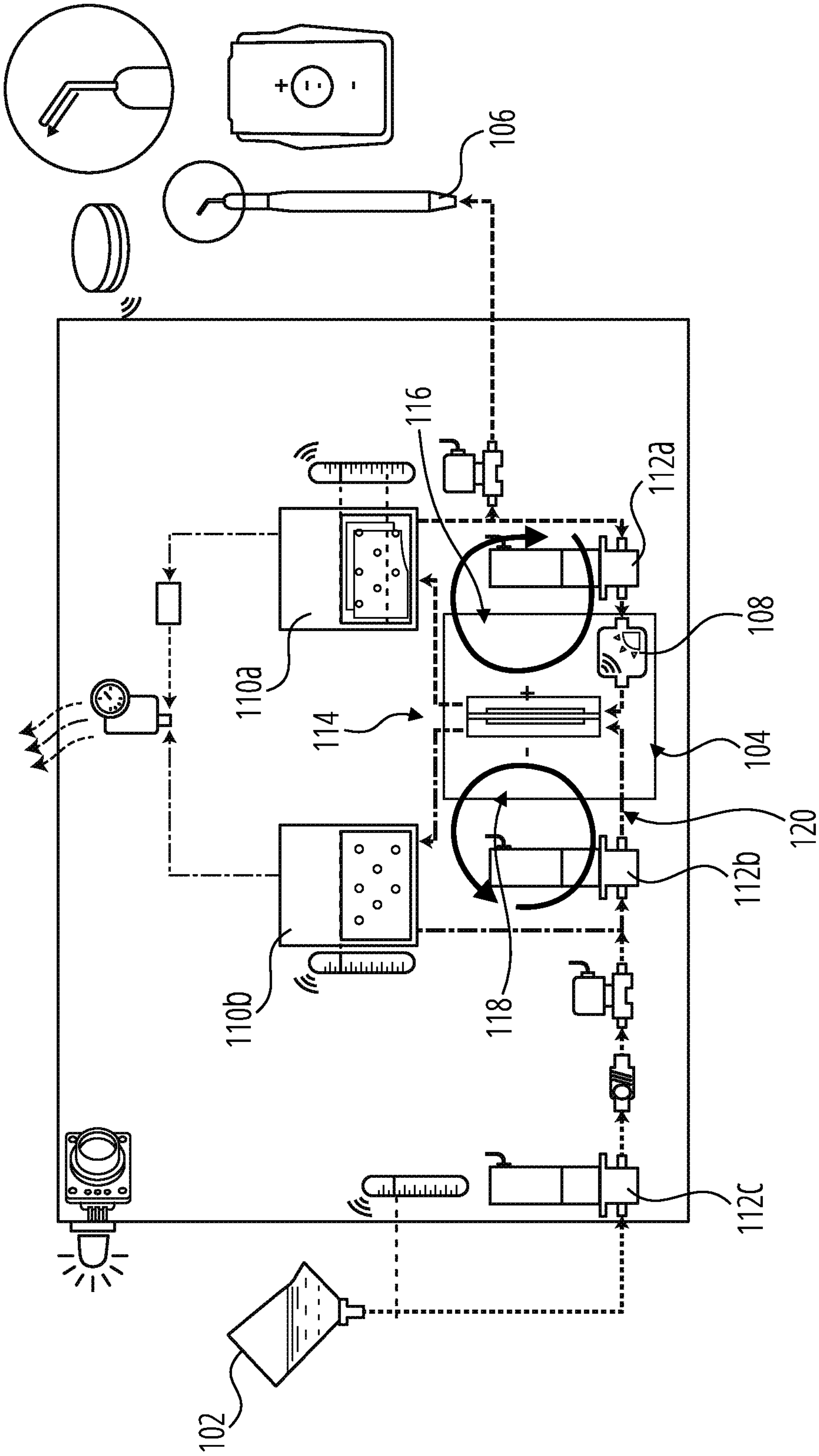


FIG. 1

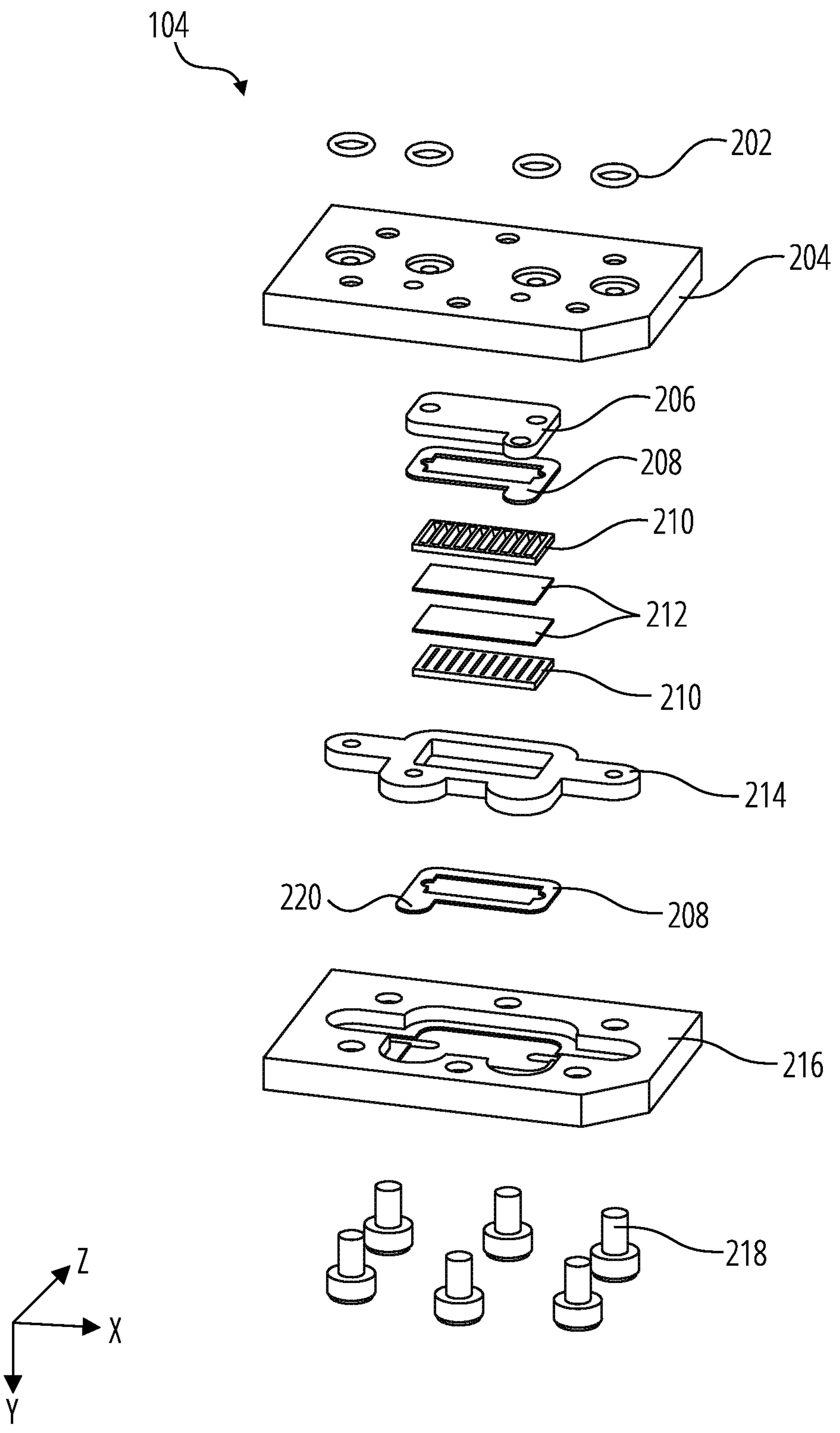


FIG. 2

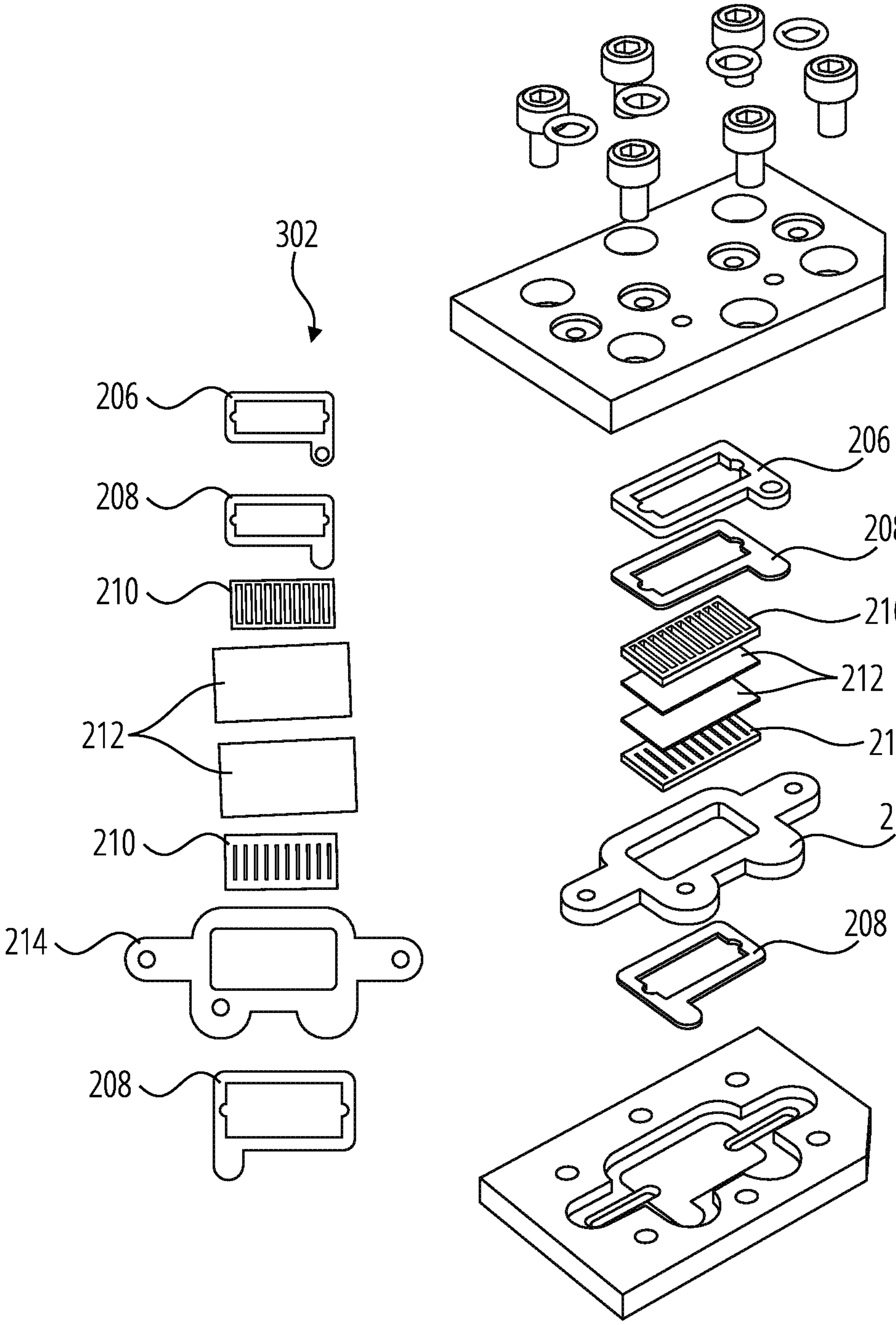


FIG. 3

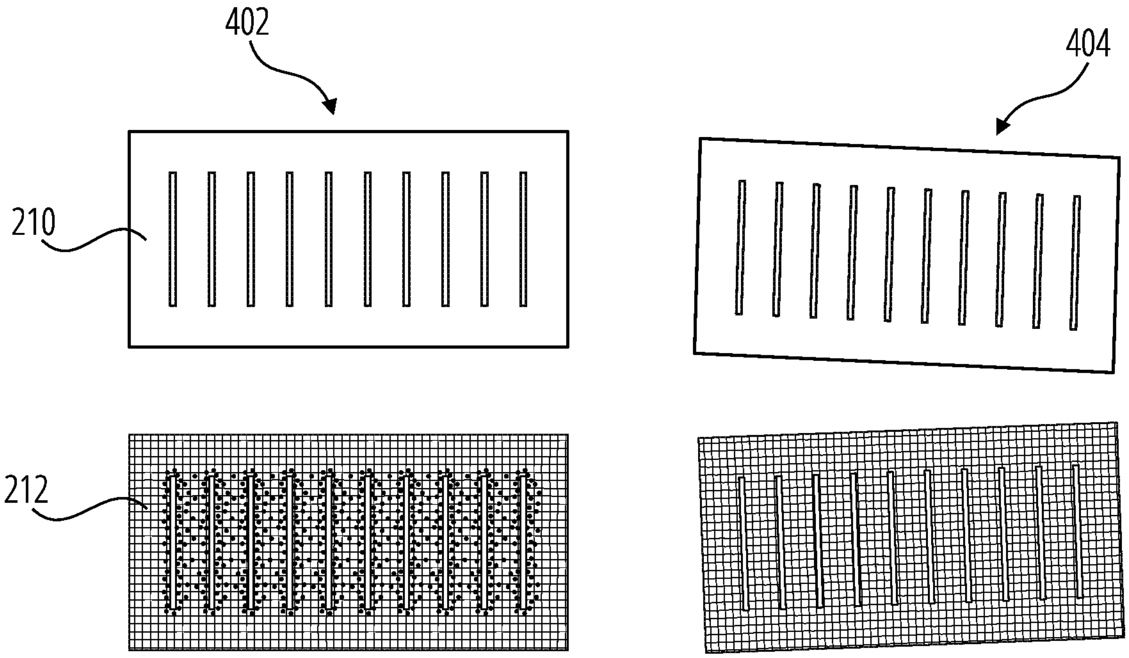


FIG. 4

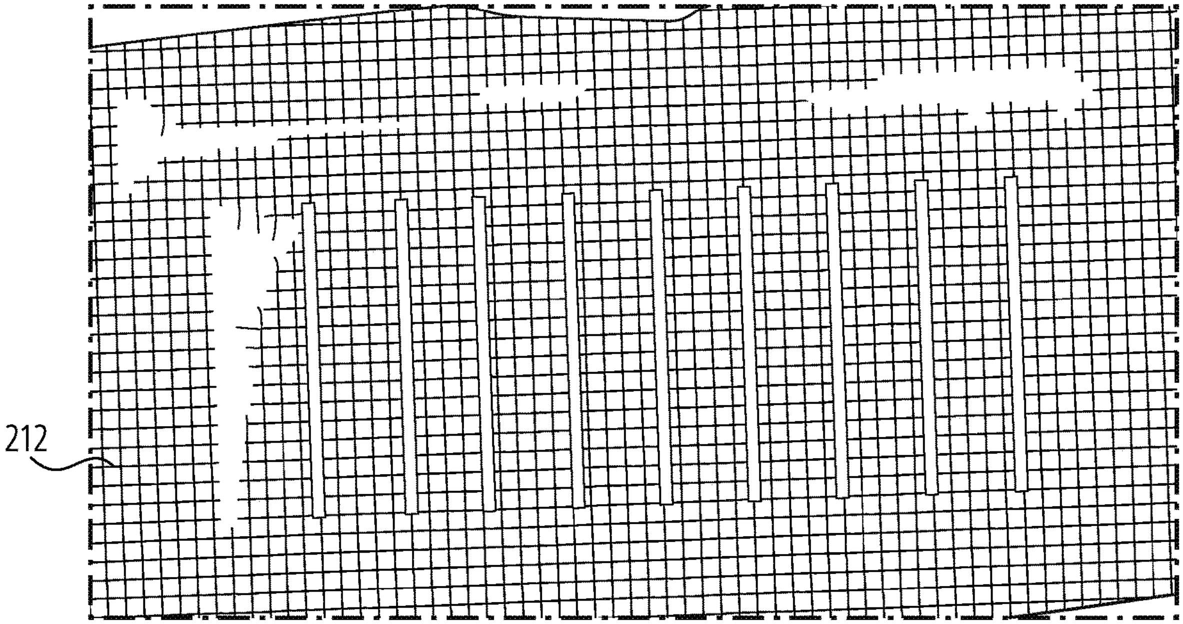


FIG. 5

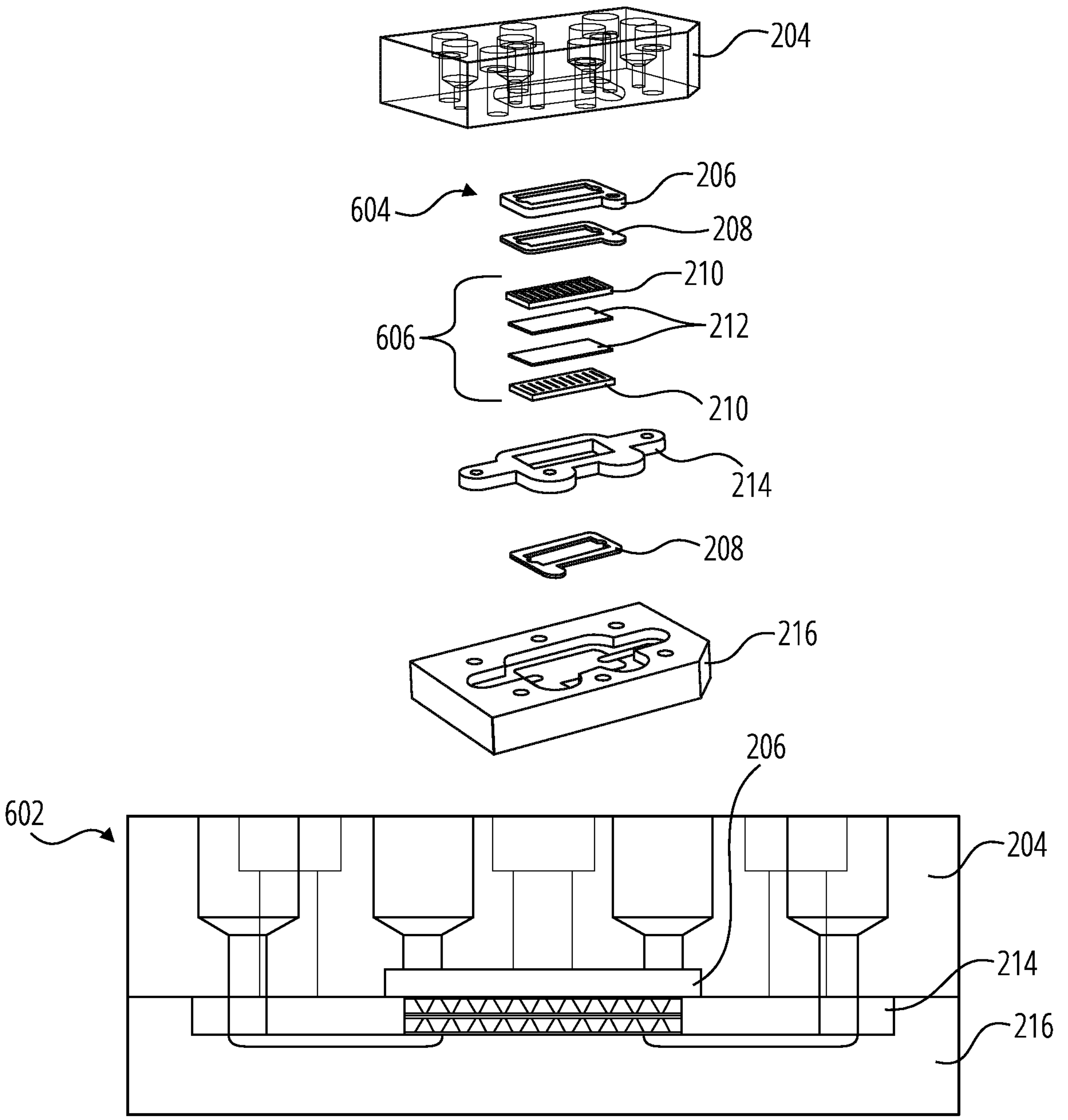


FIG. 6

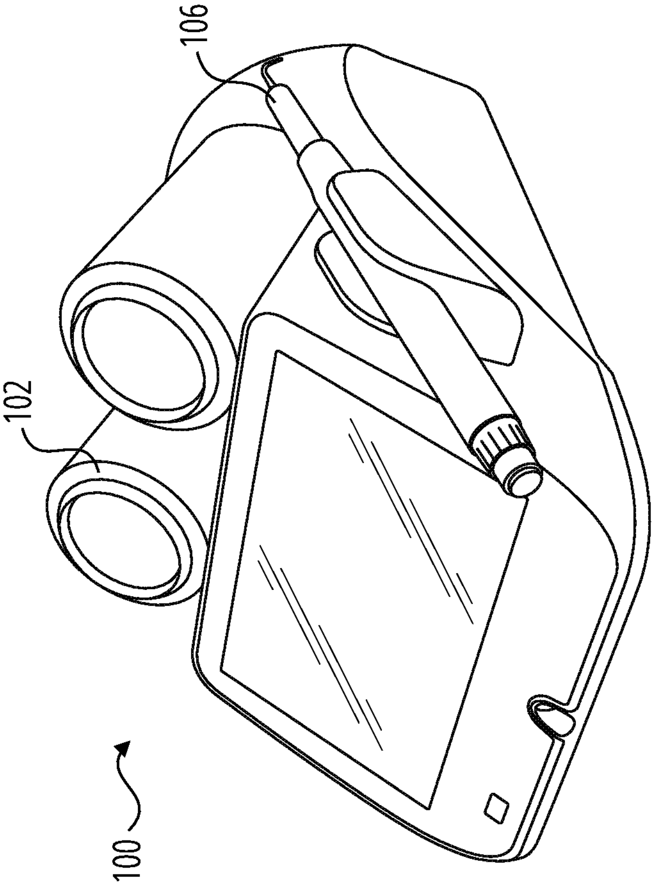


FIG. 7

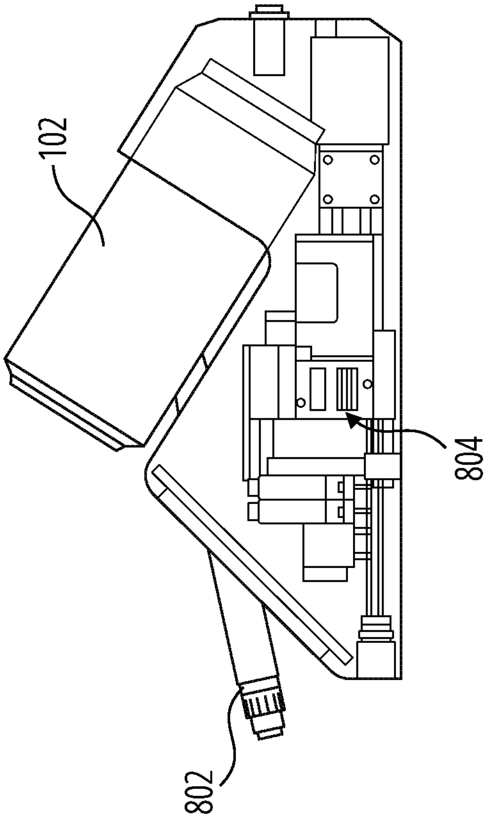


FIG. 8

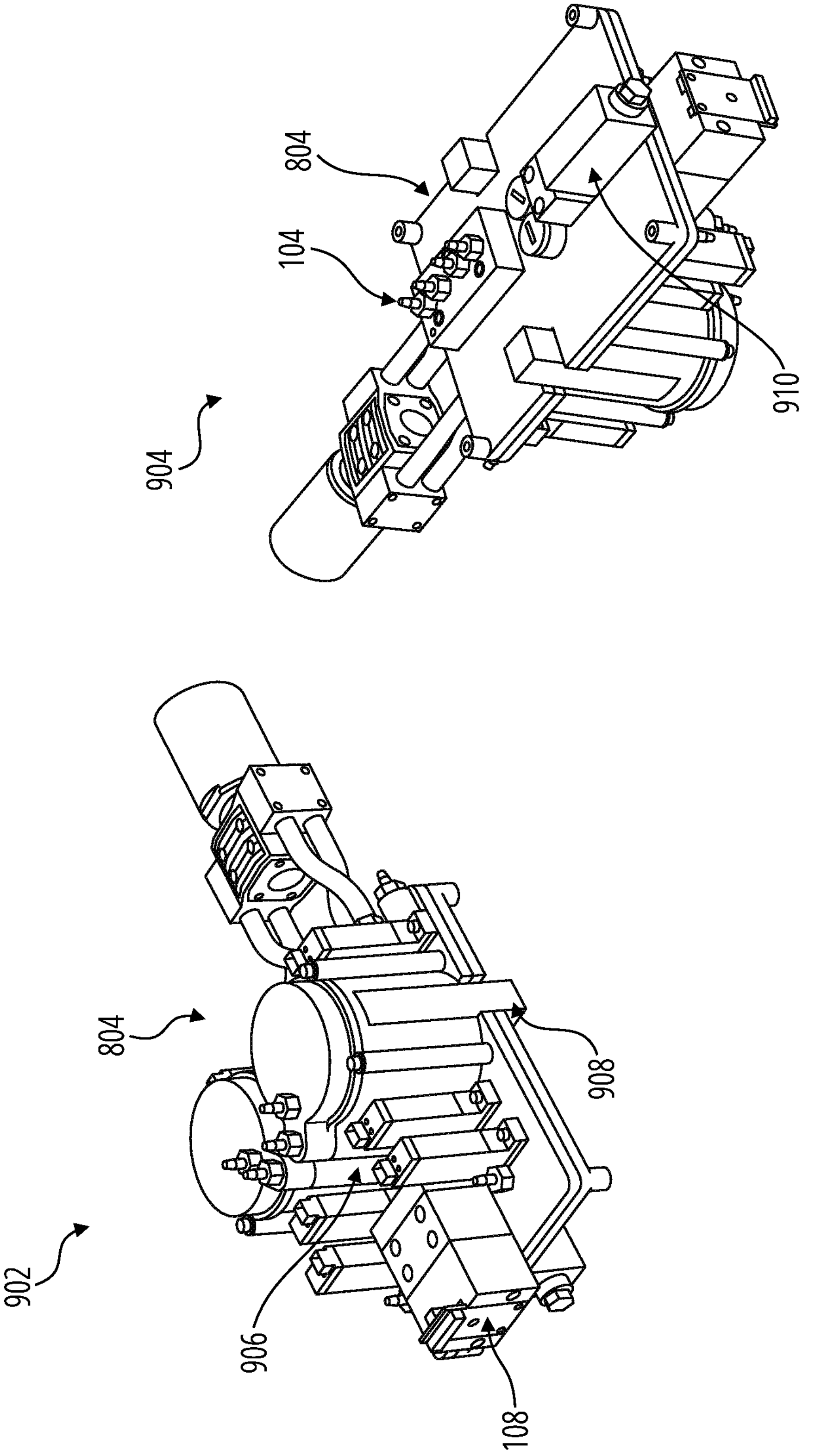


FIG. 9

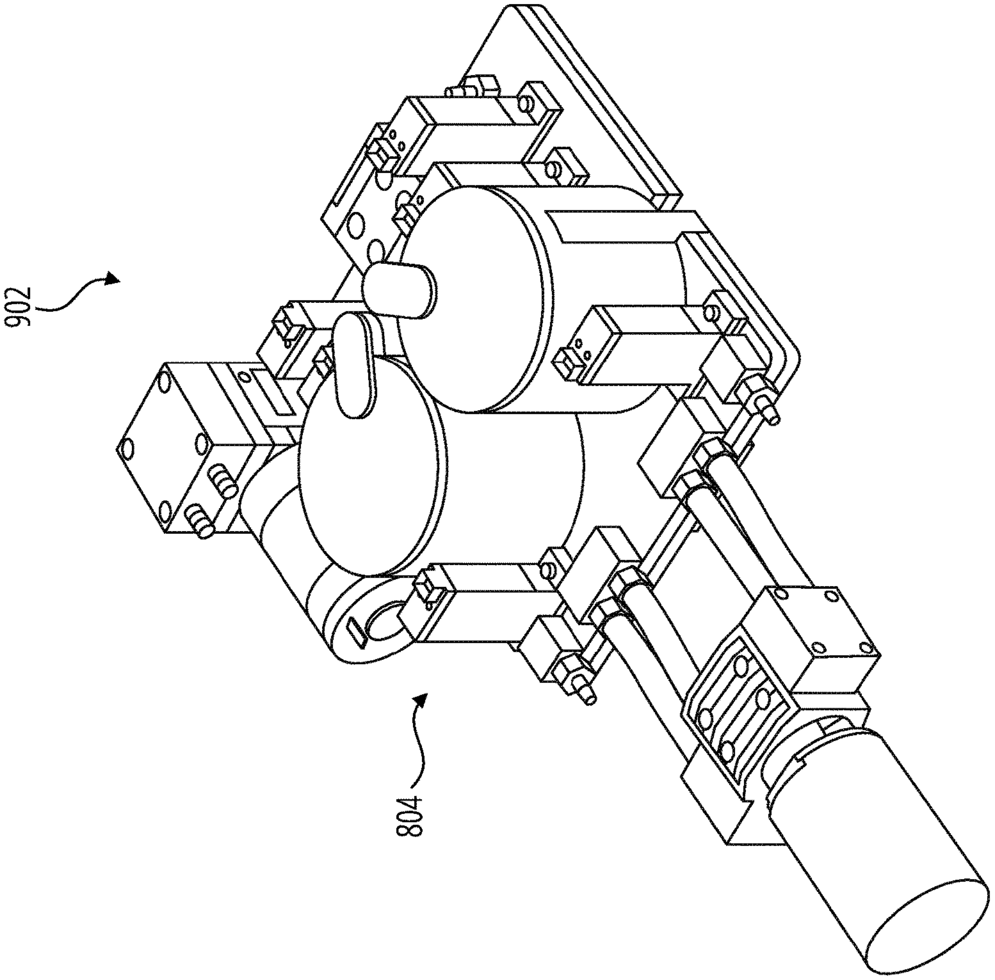


FIG. 10

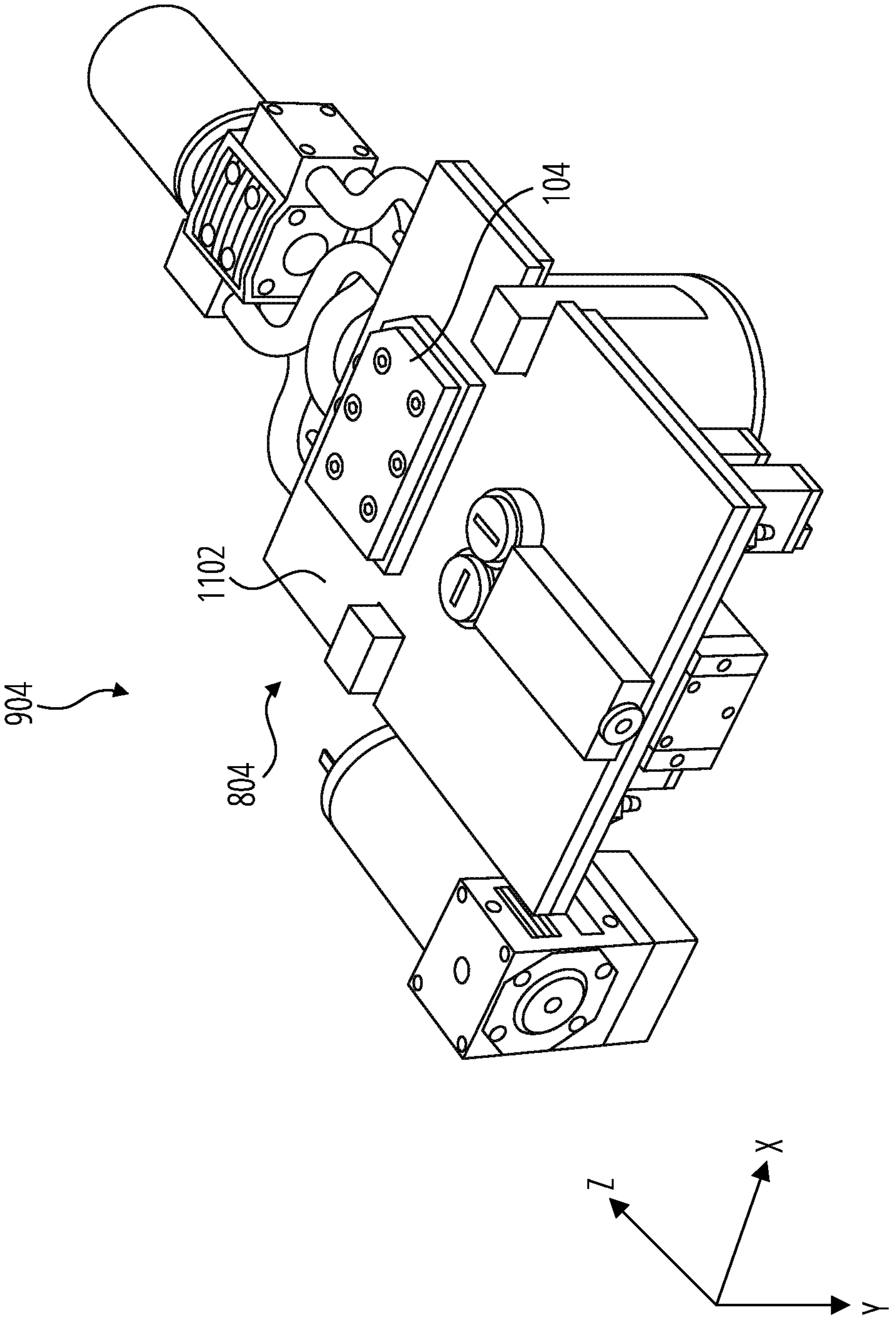


FIG. 11

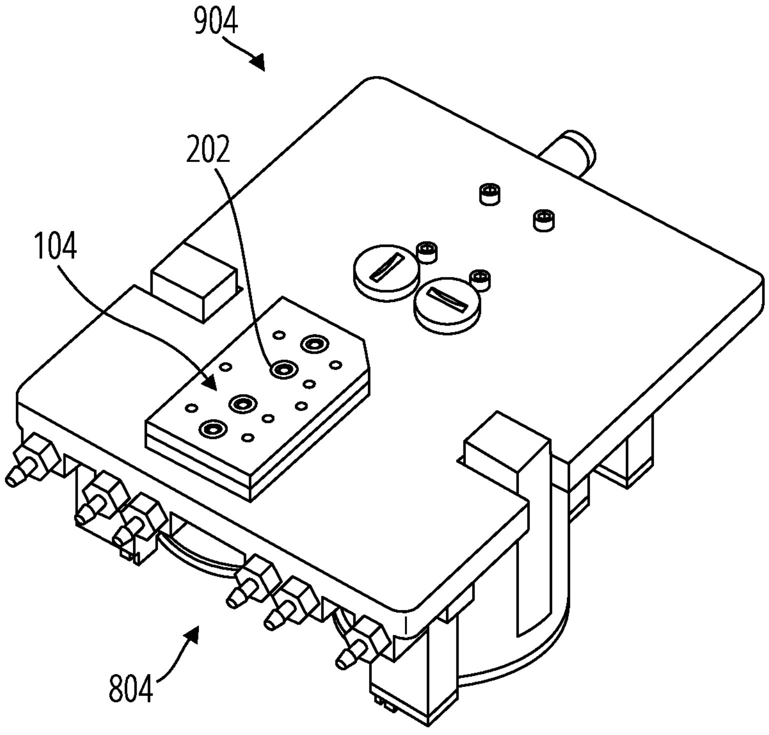


FIG. 12

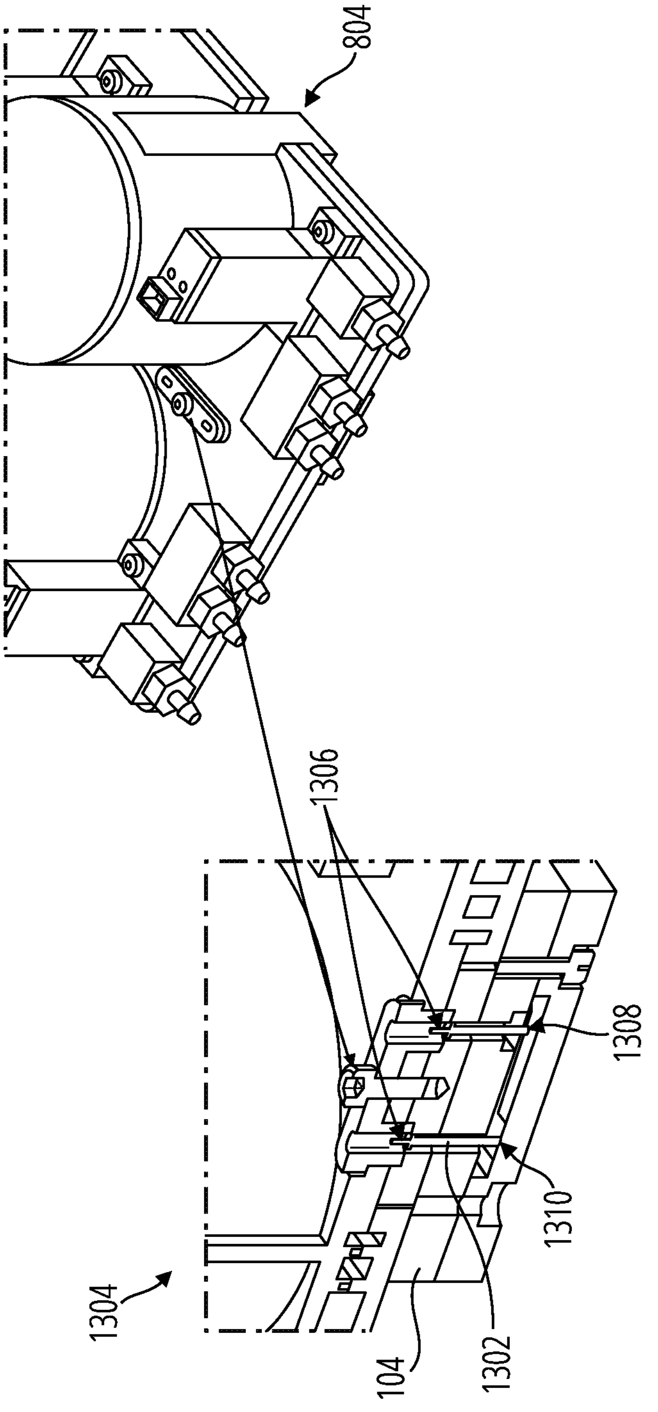


FIG. 13

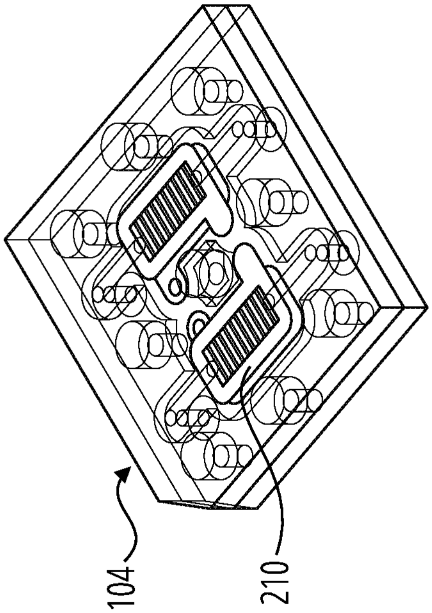


FIG. 14

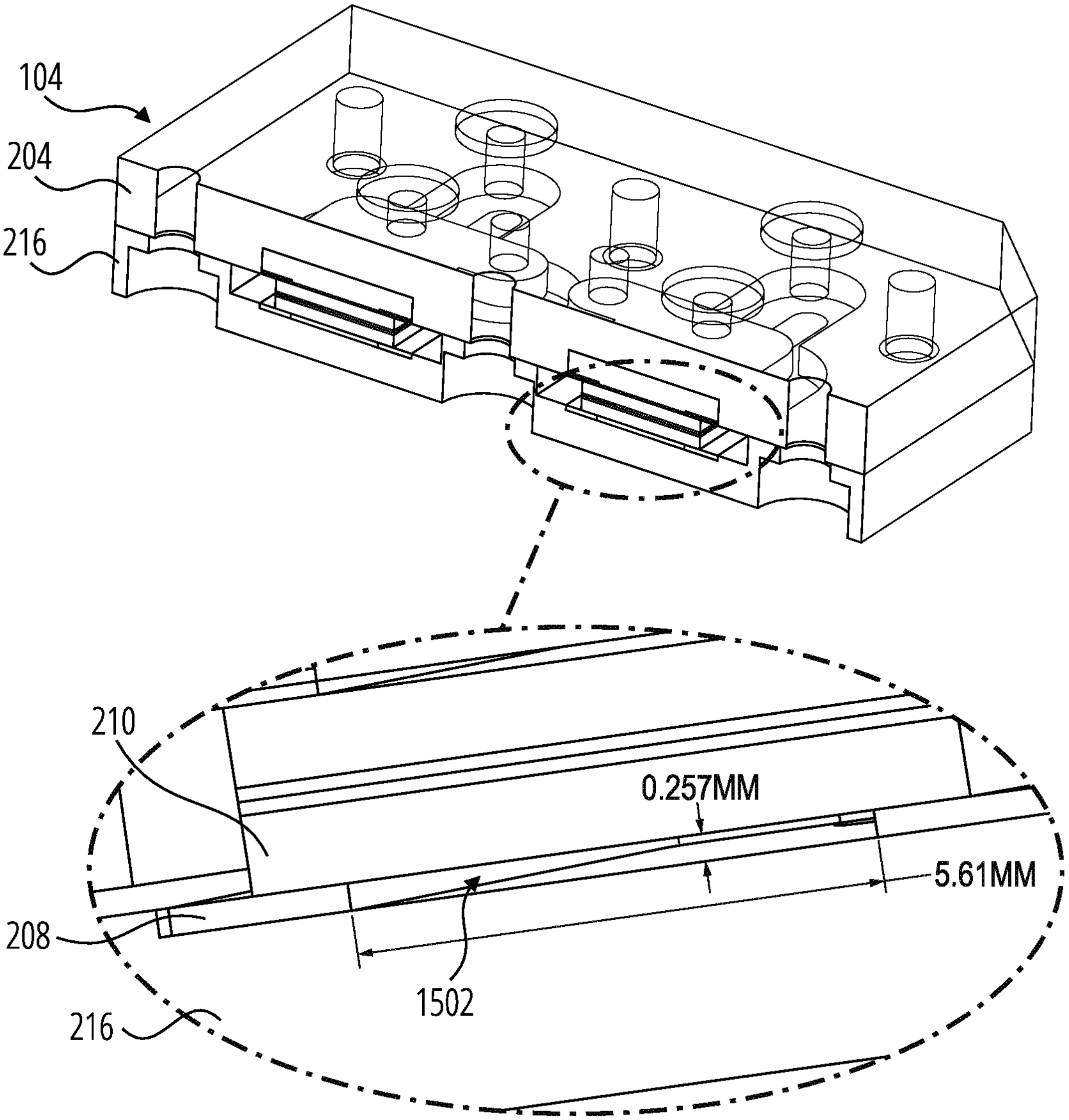


FIG. 15

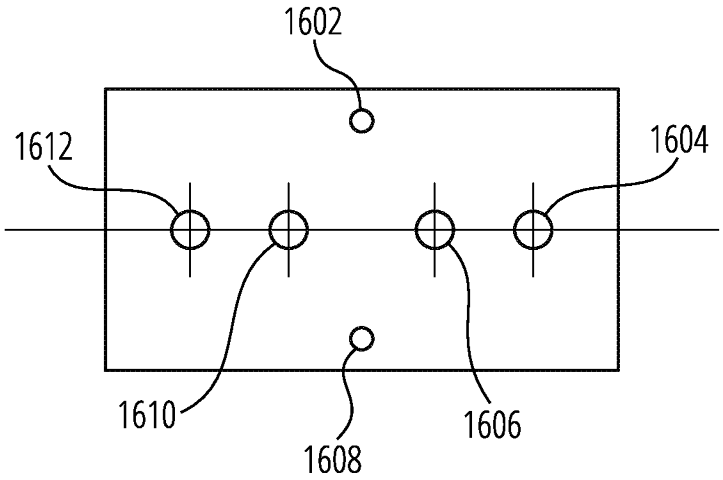


FIG. 16

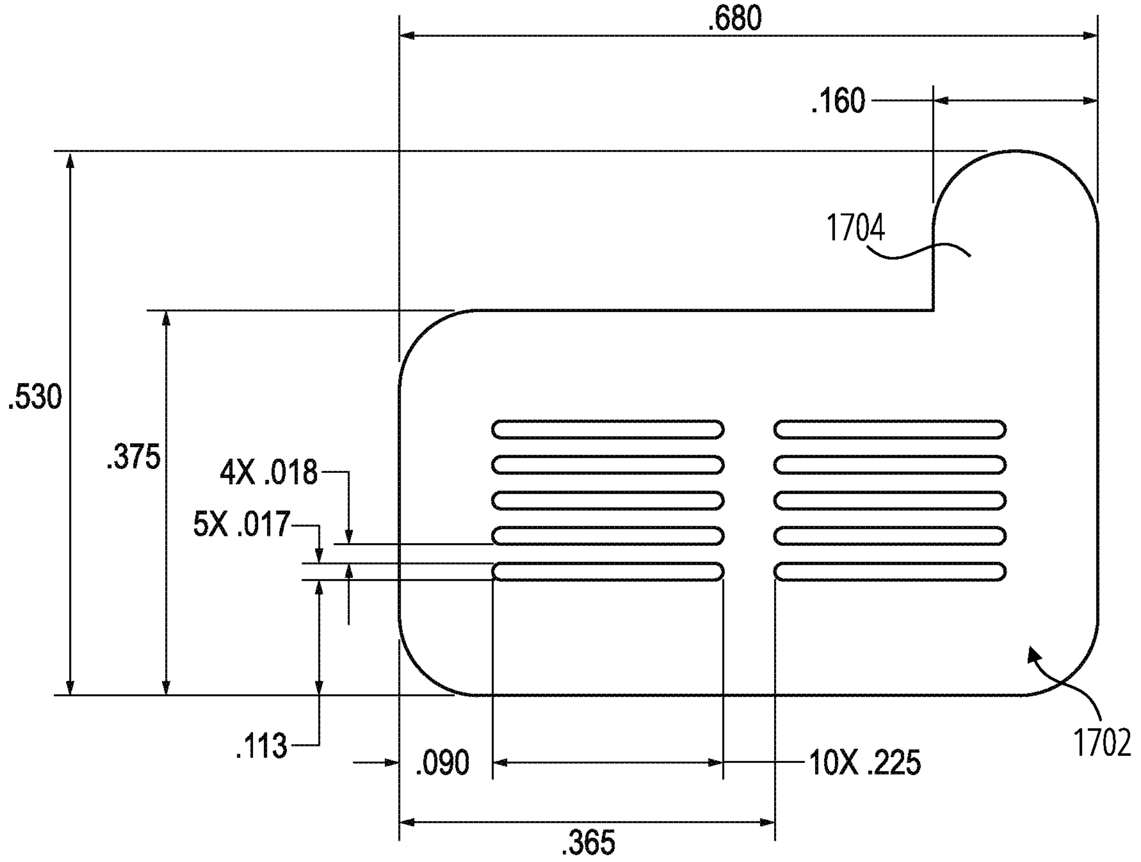


FIG. 17

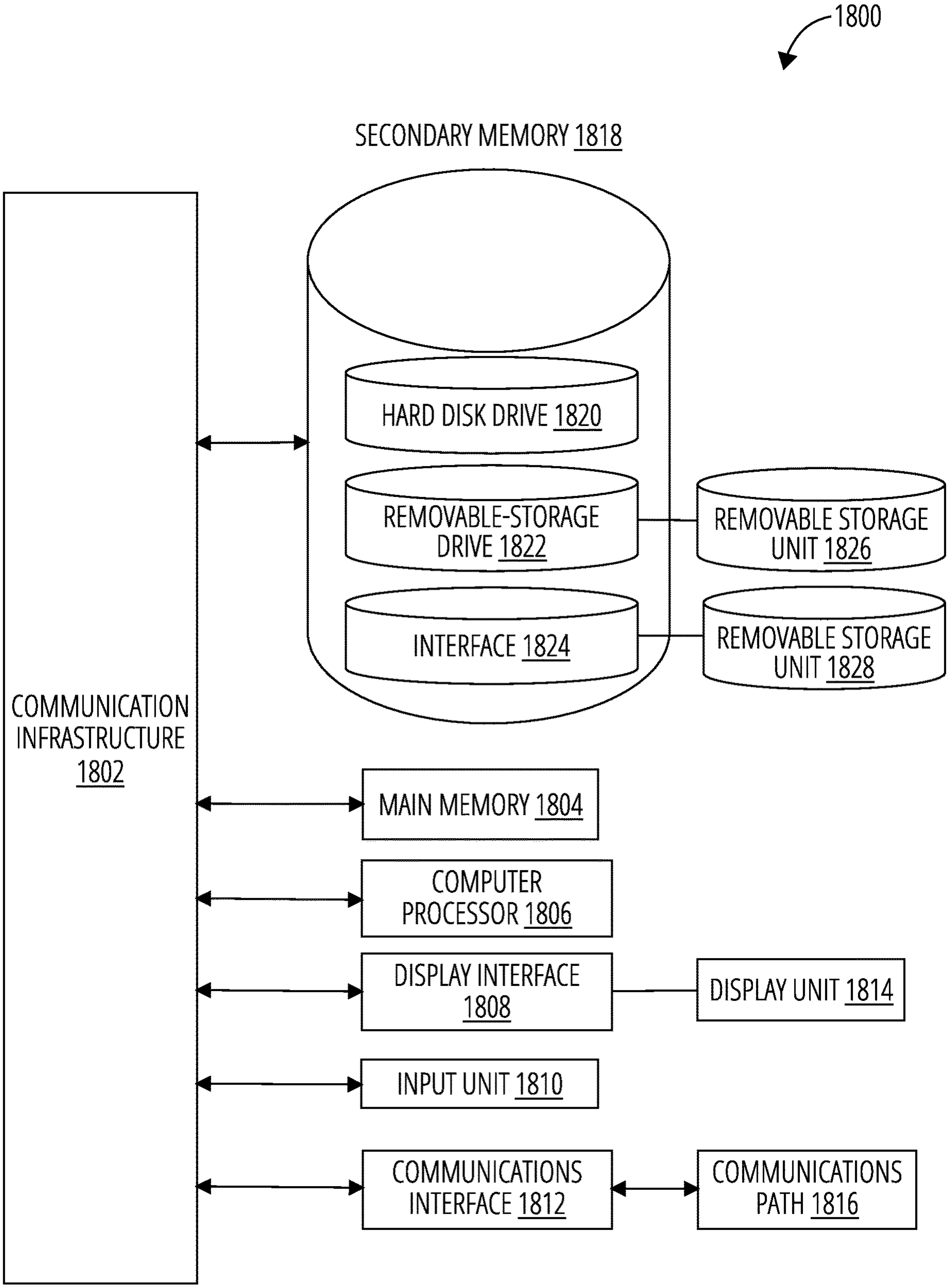

1800
SECONDARY MEMORY 1818
HARD DISK DRIVE 1820
REMOVABLE-STORAGE DRIVE 1822
REMOVABLE STORAGE UNIT 1826
INTERFACE 1824
REMOVABLE STORAGE UNIT 1828
COMMUNICATION INFRASTRUCTURE 1802
MAIN MEMORY 1804
COMPUTER PROCESSOR 1806
DISPLAY INTERFACE 1808
DISPLAY UNIT 1814
INPUT UNIT 1810
COMMUNICATIONS INTERFACE 1812
COMMUNICATIONS PATH 1816

FIG. 18

MANIFOLD COMPATIBLE ELECTROLYTIC CELL (EO CELL) WITH COPLANAR FLUIDIC AND ELECTRICAL CONNECTION SCHEME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This patent application claims the benefit of and priority to U.S. Provisional Application No. 63/086,218 filed Oct. 1, 2020, which is herein incorporated by reference for all purposes.

TECHNICAL FIELD

[0002] This application relates generally to an electrolytic ozone cell. More specifically, the application relates to a low-profile electrolytic ozone cell having a coplanar fluidic and electrical connection with a manifold assembly.

BACKGROUND

[0003] Ozone is a highly reactive gas composed of three oxygen atoms (O3). It is naturally occurring in Earth's atmosphere, with the highest concentration in the stratosphere, and acts as a filter for ultraviolet rays. Ozone is a highly effective antibacterial agent and has been used in medical applications including disinfection and sterilization products. Gaseous ozone produces an oxidative reaction on the cytoplasmic membrane and cell wall of the bacteria. The resulting damage to the cell wall of the bacteria allows increased accumulation of ozone within the cell which creates free radicals that destroy the bacteria. By taking advantage of this, significant benefits for oral health and wider systemic health, including reducing risk of caries, gingivitis and periodontitis, halitosis, cardiovascular disease, stroke, hyperglycemia, and other diseases can be achieved.

BRIEF SUMMARY

[0004] The illustrative embodiments provide a system suitable for creating ozone dispersed in a liquid such as water that is suitable for use in dental products such as a dental ultrasonic scaler.

[0005] In one aspect, an electrolytic ozone cell includes a housing including an interfacial seal, a top plate, and bottom plate. The electrolytic ozone cell also includes an internal compartment that includes at least a pair of contact plates, a tolerance compressor that compresses an electrode-membrane-electrode stack which includes a pair of electrodes and at least one proton exchange membrane, where the electrode-membrane-electrode stack is disposed between the pair of contact plates and the tolerance compressor is configured to alter the dimensions of the tolerance compressor responsive to thinning of the proton exchange membrane, in order to maintain compressive forces on at least the electrode-membrane-electrode stack. In an embodiment of the electrolytic ozone cell the electrode-membrane-electrode stack includes one or more pairs of electrodes in the same cell. The one or more pairs may each be independently controllable.

[0006] The electrolytic ozone cell may also include where a housing of the electrolytic cell is configured to be coupled to a manifold assembly of an aqueous ozone ultrasonic scaler Systems such that it has a flush coplanar interface with the manifold surface.

[0007] The pair of contact plates may be titanium (Ti) contact plates. The pair of electrodes may be boron dope diamond (BDD) electrodes. An electrode of the pair of electrodes may be a perforated silicon plate with a boron doped diamond coating. The pair of electrodes and the proton exchange membrane may form an electrode-membrane-electrode stack and the tolerance compressor provides compression for the electrode-membrane-electrode stack over a range of between 2 to 50% of the thickness of the tolerance compressor.

[0008] Further, the tolerance compressor may be inert to ozone. The tolerance compressor may also be made from a closed-cell ethylene propylene diene monomer (EPDM) foam material. A path for water flow may be based on a thickness and inner profile of a contact plate of the pair of contact plates.

[0009] The electrolytic ozone cell may include more than one pair of pair of electrodes. An electrical contact zone of a contact plate of the pair of contact plates may be accessed through the top plate by a spring-loaded electrical contact so that the contact plate provides electrical current to an electrode of the pair of electrodes. A contact plate and an electrode may be integrated together to form an electrode unit that provides direct electrical contact for a spring-loaded electrical contact. The cell may be configured to control a velocity of water that flows over an area of bubble formation along triple phase boundaries (TPB) formed by an electrode-water-membrane intersection. Other technical features may be readily apparent to one skilled in the art from the following figures, descriptions, and claims.

[0010] In one aspect, an apparatus may be formed that includes a water supply for delivering water to an electrolytic ozone cell. The apparatus also includes a gas separator disposed in a recirculation loop of a fluid pathway that also contains the electrolytic cell. The apparatus also includes the electrolytic ozone cell. The electrolytic ozone cell further includes a housing including an interfacial seal, a top plate, and bottom plate. The electrolytic ozone cell of the apparatus further includes an internal compartment that includes at least a pair of contact plates, a tolerance compressor that compresses an electrode-membrane-electrode stack which includes a pair of electrodes and at least one proton exchange membrane, where the electrode-membrane-electrode stack is disposed between the pair of contact plates, and the tolerance compressor is configured to alter the dimensions of the tolerance compressor responsive to thinning of the proton exchange membrane, in order to maintain compressive forces on at least the electrode-membrane-electrode stack.

[0011] In one aspect, a computer system is formed. The computer system includes a processor configured to control an operation of an electrolytic ozone cell. The computer system also includes the electrolytic ozone cell. The computer system also includes the electrolytic ozone cell which further includes a housing including an interfacial seal, a top plate, and bottom plate. The electrolytic ozone cell of the computer system further includes an internal compartment that includes at least a pair of contact plates, a tolerance compressor that compresses an electrode-membrane-electrode stack which includes a pair of electrodes and at least one proton exchange membrane, where the electrode-membrane-electrode stack is disposed between the pair of contact plates, and the tolerance compressor is configured to alter the dimensions of the tolerance compressor responsive to thinning of the proton exchange membrane, in order to maintain compressive forces on at least the electrode-membrane-electrode stack. Other technical features may be readily apparent to one skilled in the art from the following figures, descriptions, and claims.

[0012] Even more specifically, in an aspect herein, a manifold compatible electrolytic ozone (EO) cell with coplanar fluidic and electrical connection scheme is disclosed. The EO cell may be designed for use in both dental and medical applications. The cell, as described herein may communicate to a broader system via a coplanar connection scheme. Thin stacked layers of the cell are assembled to form a low-profile assembly. The cell is designed to communicate via fluidic and electrical ports arranged on one single plane of the cell. The low-profile design and coplanar connection scheme deliver a form factor that is easily accessible for service and helps to limit the overall footprint and form factor of the medical device.

[0013] One example of use for such an electrolytic cell is the production of aqueous ozone in a dental ultrasonic scaler. Such a scaler is equipped with a closed system water delivery and an integrated in-line electrolytic ozone generator, gas separation, in-line dissolved gas monitoring which enables closed loop control over ozone concentration. The EO cell enables the ultrasonic scaling unit with the ability to generate aqueous ozone (AO) Solution on demand, addressing key market barriers. An ultrasonic scaling system that utilizes aqueous ozone lavage enhances the removal of dental biofilm for more complete debridement. Aqueous ozone will be delivered to the oral cavity through the ultrasonic scaler handpiece and insert, which will be controlled through the ultrasonic scaling unit.

[0014] A fully integrated system with inline aqueous ozone generation enables aqueous ozone to be generated and used in the operatory when needed for a dental or medical procedure. The materials used in a fluidic path for both the aqueous ozone generator and the scaler can be controlled and engineered to limit both scavenging and assuring material compatibility with the dissolved ozone, controlling the concentration of the lavage that exits the scaling instrument, assuring efficacy and the reliability of the equipment. Integrating the ozone generator and ultrasonic scaler prevents the misuse of aqueous ozone in existing scalers that are potentially incompatible with ozone.

[0015] Dental professionals would be able to use the ultrasonic scaling unit with or without generating aqueous ozone. Having the ability to turn off the ozone production or lower it so that it only maintains the cleanliness of the waterlines provides the clinician with the ability manage when they deliver aqueous ozone to their patients.

[0016] A manifold compatible EO cell as described herein has several advantages. By communicating with the manifold through a coplanar interface all fluidic and electrical connections can be formed by securing the EO cell to the surface of the manifold, eliminating additional interconnection componentry, reducing size, improving reliability, and creating a more easily accessible and serviceable design. In addition, the cell construction utilizes a tolerance compressor element that manages both least and maximum material conditions as well as the loss of membrane thickness over the life of the cell.

[0017] Form Factor

[0018] Ultrasonic scalers typically sit on countertops, in cabinets, or special drawers designed for the operatory equipment. These standard installation locations for a scaler demand that any new scaler, regardless of the technology, have the form and fit necessary for the existing operatories. This practical consideration drives the overall industrial design of the scaler, its height and footprint. As a result, the internal components that are used to generate and control the AO solution must be compact. The manifold compatible EO Cell provides such a low-profile form factor, while at the same time making it easily accessible for use via a service door or panel on the scaler housing.

[0019] Optimum Flow Rate for the EO Cell Design (Bubble Clearance Via Restricted Path Flow Path)

[0020] The design of the cell also controls the velocity of water that flows over the area of bubble formation along the triple phase boundaries (TPB) formed by the electrode-water-membrane intersection. The cell design channels water over the TPB at an ideal velocity based on the system internal recirculation flow rates. Lower flow rates in the overall system recirculation path reduces wear and tear on the systems water pump and minimizes turbulence in the gas separator, directly supporting the gas separators' ability to allow gravity and laminar flows to prevent bubbles from re-entering the recirculation path or exiting the system and traveling to the scaler handpiece. The prevention of bubbles from being recirculated improves the precision of a UV sensor that utilizes the absorption properties of the dissolved ozone molecule in order to quantify the concentration level of the aqueous ozone. Bubbles that travel through the UV sensor tend to scatter light and add noise to the UV sensor's measurement. The efficiency of the system to convert electrical current into aqueous ozone is directly related to the system reliability, in addition to the mechanical wear and tear and the recirculation pump. The cell design controls the fluid velocity through the cell, by optimizing this flow rate we can minimize the recirculation rate and limit the mechanical decomposition of the ozone molecule. Mechanical pumping and recirculation of the AO solution aids in the decomposition of O3 back to the more stable oxygen state O2. Therefore, efficient cell operation at lower recirculation rates improves the overall system efficiency, reducing the demand and current density on the cell, and increasing the EO cell and overall system reliability.

[0021] A critical parameter is the flow velocity in the cell. Flow velocity is controlled primarily by a combination of flow rate and the gap between above the electrode or the bubble clearance. Cells designed for high volume through put (e.g., 1 Liter per minute or more) may have a large bubble clearance, however these cells would not be optimized for a system that uses lower flow rates to recirculate the aqueous ozone in order to achieve and control a desired concentration while also removing undissolved gas from the output fluid stream. Higher volume through put cells have about 1 m/sec fluid velocity across the electrode, and at higher flow rates bubbles can be effectively be purged from the TPB. The exact value necessary for purging gas from the TPB is dependent on the surface geometry of the electrode, the size of the gap vs the size of the bubbles, and the current density that the cell is operating at also determines the growth rate and quantity of gas production.

[0022] For example, assuming a 1 m/sec fluid velocity across the face of the cell and calculating this based on the flow path geometry and the volume flow rate. A 5 mm wide and 0.1 mm high flow path across an electrode, the nominal flow speed is easily estimated—cross section area is (0.5*0.01) cm2=0.005 cm2.

[0023] In this very narrow gap, the flow speeds get above 1 m/sec even at rates much less than 200 ml/min recirculation rate.

Split cell narrow gap flow speeds vs volume rate
Estimated Cell gap width 0.561 cm
Estimated Gap depth 0.0257 cm
Flow path area 0.0143 cm2

Volume rate (ml/min)	Speed across electrode (m/sec) (Volume rate/flow path area = speed across electrode)			
20	23.1	cm/sec	0.2	m/sec
40	46.2	cm/sec	0.5	m/sec
60	69.4	cm/sec	0.7	m/sec
80	92.5	cm/sec	0.9	m/sec
100	115.6	cm/sec	1.2	m/sec
120	138.7	cm/sec	1.4	m/sec
140	161.8	cm/sec	1.6	m/sec
160	185.0	cm/sec	1.8	m/sec
180	208.1	cm/sec	2.1	m/sec
200	231.2	cm/sec	2.3	m/sec

[0024] Therefore, reducing the bubble clearance will support recirculation rates <100 ml/min from the bubble-removal point of view. Other than the bubble-removal perspective the effects of the flow rate on the separator is considered, wherein bubbles are prevented from entering the output and being recirculated while also mixing the nascent AO solution with the volume of fluid in the separator. The interaction between recirculation rate and the concentration-averaging timescale in the separator depends on what concentration fluctuation behavior is acceptable, and this also depends on what refill cycle is used to maintain fluid levels in the separator during AO solution output from the handpiece.

[0025] Gas build-up caused by bubble entrapment in the cell flow path can occur if the flow rate through the cell gets too low in the electrode area. The water flow also has to remove the heat from the cell, so in the limit of low flow, one must consider the effects on internal cell temperature which is also mitigated by modulation of the cell current and toggling between cell pairs in a dual electrode pair cell configuration. The EO Cell may not have a pure transverse flow, and so there may be "eddies" in the periphery that can trap some bubbles—but the majority of the electrode area is well flushed by the flow. The orientation of the cell such that its output ports are terminated to the bottom of the manifold lends itself to the release of any bulk bubble formation, gas build-up outside the flow path, this bulk bubble formation would migrate because of both system recirculation flow, interruption in recirculation during the separator fill cycle, and the effects of gravity.

[0026] In addition, lower recirculation flow rates create a quieter product by limiting both motor and pump noise in the dental operatory.

[0027] Reliability

[0028] The elimination of additional interconnection componentry directly lends itself to improved reliability. A single interfacial seal for just one fluidic port, replaces two fittings, each of which has two connections a rigid and tube interface. Four potential leak points per fluid port can be addressed through a single precision coplanar connection. A cell will typically have four fluidic ports (anode in and out and cathode in and out) creating the potential for fluid leaks. To demonstrate the reliability improvement, consider that each connection, not being redundant has a reliability of 99.0% over the useful life of the product. This reliability must be considered for each of the fluidic joints in the system used to terminate a cell (4 ports, 8 fittings, 8 tube connection, 8 rigid connections) (0.99ˆ16=0.851), which lowers the system reliability to 85.1%. The coplanar seal has four ports and four seals, assuming the same reliability of 99%, the overall cell reliability would be 96%. It can also be argued that the nature of fittings and the dependence on the skill and training of the assembler may impact the overall reliability of a connection (e.g., inadequate torque on a fitting, improper seating of a tube, failure to secure a tube with the correct sleeve or tube lock). The manifold compatible EO cell can be inspected and secured using redundant mounting hardware to accommodate compression of the interfacial seals.

[0029] Tolerance Compressor

[0030] The cell construction utilizes a tolerance compressor that maintains normal force on the electrode pair improving the EO cell reliability and performance. The tolerance compressor element manages both the least material conditions, maximum material conditions for the cell components, any thermal expansion, and the loss of membrane thickness over the life of the cell. In addition to absorbing dimensional variability, it assures that the final cell assembly has adequate internal compression forces on the electrode-membrane-electrode stack. The clamping force on the stack-up assures the proper cell impedance and good contact area over the surface of the electrodes.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0031] To easily identify the discussion of any particular element or act, the most significant digit or digits in a reference number refer to the figure number in which that element is first introduced. Certain novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further objectives and advantages thereof, will best be understood by reference to the following detailed description of the illustrative embodiments when read in conjunction with the accompanying drawings, wherein:

[0032] FIG. **1** depicts a block diagram of an aqueous ozone ultrasonic scaler system **100** in accordance with one embodiment.

[0033] FIG. **2** depicts an exploded view of a manifold compatible electrolytic cell in accordance with illustrative embodiments.

[0034] FIG. **3** depicts an inner components image of a single electrode pair manifold compatible electrolytic cell in accordance with an illustrative embodiment.

[0035] FIG. **4** depicts an image of electrodes and membranes in accordance with an illustrative embodiment.

[0036] FIG. **5** depicts a membrane image demonstrated degradation and thinning in accordance with an illustrative embodiment.

[0037] FIG. **6** depicts an image of a tolerance compressor element and electrolytic cell cross section in accordance with an illustrative embodiment.

[0038] FIG. **7** depicts a perspective view of an ultrasonic dental scaler with integrated ozone generators in accordance with an illustrative embodiment.

[0039] FIG. **8** depicts transparent housing views in accordance with an illustrative embodiment.

[0040] FIG. **9** depicts a top and bottom perspective view of the manifold assembly in accordance with an illustrative embodiment.

[0041] FIG. **10** depicts a top perspective view of a manifold assembly in accordance with an illustrative embodiment.

[0042] FIG. **11** depicts a bottom perspective view of a manifold assembly in accordance with an illustrative embodiment.

[0043] FIG. **12** depicts a bottom perspective view of a manifold assembly showing electrolytic cell location in accordance with an illustrative embodiment.

[0044] FIG. **13** depicts a cross sectional view of manifold assembly showing electrolytic cell electrical connections in accordance with an illustrative embodiment.

[0045] FIG. **14** depicts an electrolytic cell built with two pairs of electrodes in accordance with an illustrative embodiment.

[0046] FIG. **15** depicts a cross-sectional image of a cell showing bubble clearance gap above electrode in accordance with an illustrative embodiment.

[0047] FIG. **16** depicts a sketch of an electrolytic cell footprint with symmetrical fluidic and electrical connections in accordance with an illustrative embodiment.

[0048] FIG. **17** depicts a sketch of an electrode with a tab to provide direct electrical contact in accordance with an illustrative embodiment.

[0049] FIG. **18** depicts a computer system in accordance with illustrative embodiments.

DETAILED DESCRIPTION

[0050] The illustrative embodiments described herein are directed to a manifold compatible electrolytic ozone (EO) cell with coplanar fluidic and electrical connection scheme. The illustrative embodiments recognize that a goal in conventional electrolysers is to produce pure hydrogen and high pressures, so a very robust structure is required. This design goal means is not suitable for low cost and portable devices. The illustrative embodiments further recognize that conventional electrolysers generally achieve very low levels of dissolved ozone in the solution, due to the requirement to avoid releasing excessive gaseous ozone, the absence of gas management components in the system, and their operation at ambient pressure.

[0051] FIG. **1** depicts a block diagram of a general aqueous ozone ultrasonic scaler system **100** in which an electrolytic ozone cell **104** may be embedded in accordance with one embodiment. The system includes a water supply **102** and an electrolytic ozone cell **104** that oxidizes the water to form ozone in solution. During startup the system attains a defined pressure by two means, a primary water pump **112***c* and/an air pump **112***a* (or air pump **112***b*) to drive fluid to a scaler/ultrasonic handpiece **106**. A gas separator **110***a*, gas separator **110***b* separates gaseous ozone from the flow of water delivered to the ultrasonic handpiece **106**. UV sensor **108** directly monitors the level of ozone in the water. Non-ozonated operation can also be delivered through the ozone generator **114** portion of the system by turning off the current to the electrolytic ozone cell **104**, the cell current can also be operated at a significantly lower level or pulsed infrequently at a current necessary to produce ozone, so that a non-detectable level of ozone is delivered to maintain the cleanliness of the waterlines in the system.

[0052] To support form factor and serviceability requirements, a low profile manifold compatible electrolytic ozone cell **104** is disclosed that minimizes space requirements while delivering an EO cell that can fully charge a dental system from, for example, 0 ppm to 6 ppm of ozonated water within a short period of time compared to conventional solutions (e.g., within 30 seconds). This ozone gas production rate and long life is achieved by maintaining a low current density on the membrane and efficiently releasing bubbles as the form at the triple phase boundary (electrode-membrane-water junction). The efficient bubble release is achieved by controlling the water velocity over the face of the electrodes. By controlling the cross-sectional area in the electrode region and maintaining both system pressure (e.g., 19-24 psi, typically 22 psi) and the flow rate through the cell. The velocity of the water in the cell can be controlled to help remove bubbles and replenish the TPB with fresh water to continue feeding the electrolytic process.

[0053] The system of the present disclosure comprises the following main elements. A housing made up of an interfacial seal **202**, top plate **204**, and bottom plate **216**, when joined form the main body of the electrolytic ozone cell **104**, defines the dimensions of the inner compartment of the electrolytic ozone cell **104**, provides a means for securing the cell to a manifold surface, creates internal fluid paths, and provides a coplanar interface for connecting both fluid and electrical current. The electrolytic ozone cell **104** may have several internal components: Tolerance compressor **206**, contact plates such as Ti contact plates **208** (Titanium contact plates), electrodes such as BDD electrodes **210** (Boron Doped Diamond electrodes), proton exchange membranes **212**, and inner bottom gasket/seal **214**. BDD has the overpotential to create ozone. In alternative embodiments, materials that are suitable for medical devices may be used. For example, lead oxide makes ozone but may not be used as it is poisonous. These internal components establish the electrolytic cell, the distribution of current in the cell, seals for separating inner fluid and gas pathways (i.e., anolyte and catholyte) and a means for maintaining adequate compressive forces on the inner assembly. Additional elements may be added without changing the essentials of the system disclosed herein. Methods and embodiments for each of these elements are detailed herein.

[0054] Conventional cells may also produce some oxygen as a byproduct, which further increases the utility of the produced water for treatments targeting anaerobic organisms but does not decrease the value of the AO solution for the primary purpose of scaling. Cells may also produce some hydrogen peroxide, and this component of the solution is also beneficial for cleaning, bleaching, and antimicrobial effects. In some cases, a synergistic effect of ozone and hydrogen peroxide is known and can be advantageously used by the system.

[0055] The Electrolytic Cell

[0056] Electrochemical ozone generation by direct oxidation of water, in place of the formation of O3 from O2 as in the gas phase, is a complex electrochemical process in which the catalytic electrode surface is the site of a network of reactions via several different adsorbed intermediates. The network of reactions produces a mixture of oxygen and ozone. The chemical properties of the catalyst surface affect the proportion of ozone production, but the oxygen-forming pathway is energetically more favorable and typically at least half of the electrode current forms oxygen even on the most ozone-promoting surfaces. The microscopic physical chemistry of the process is not fully understood, even though the relative ozone vs oxygen forming rates of different catalysts have been extensively studied and large differences observed.

[0057] Conventionally, a goal has been to achieve as high a rate of oxygen evolution (and hence hydrogen production) as possible, at the lowest achievable cell voltage, because this directly influences the energy cost of the process. Much of the electrolysis is done directly, with a conductive electrolyte carrying the current between the electrodes. However, a proton-conductive membrane to carry a proton current but that does not allow other species to pass at appreciable rates can be used herein. This allows electrolysis of pure water to be achieved, with significant advantages in terms of chemical simplicity and absence of unwanted byproducts. The proton conductive membranes may be sulfonated derivatives of Teflon, such as Nafion, Aquivion, and similar products. These cells are usually called Proton Exchange Membrane Water Electrolysers (PEMWE).

[0058] Conventional PEMWE industrial cells in e.g., the Membrel process for oxygen/hydrogen production have cell voltages which when are increased and ozone-selective catalysts are used, have their achievable working lifetime decreasing considerably, due to membrane and electrode degradation in the extremely oxidizing environment, and in particular due to some free radical mediated reactions that effectively attack the membrane polymer.

[0059] The selective formation of ozone instead of oxygen has hydrogen as a waste product, and the target of the present disclosure is not necessarily the lowest energy cost but rather the combination of a high dissolved ozone concentration and a long working lifetime of the cell. To achieve this objective, electrodes of boron doped diamond can be used, to take advantage of this material's preferential ratio of ozone to oxygen formation. However, BDD as a material presents some practical challenges, as it is essentially equivalent to diamond in terms of mechanical properties and has to be made by direct synthesis of a doped diamond layer on a suitable substrate to form a layer of controlled conductivity. Thus, a BDD electrode may be relatively expensive and fragile. Though platinum may be used in some circumstances, platinum oxides may pollute the membrane over time.

[0060] In one embodiment, the cell **104** includes a pair of perforated silicon plates with a thin boron doped diamond coating, the thin boron doped diamond coating being from, for example, less than 100 nm up to 15 typically 5 and can be coated more than 25 μm with a layer of proton conducting membrane **212** between them, and flow passages for the water and released gases to pass over the perforated surfaces. This configuration provides the necessary 3-phase boundary regions at the edge of every hole in the plate. Thus, the BDD electrode may be a perforated silicon plate with a boron doped diamond coating.

[0061] System Level Polarity Switching

[0062] One embodiment of the system described herein includes a design where both the cathode recirculation path **118** and the anode recirculation path **116** of the electrolytic ozone cell **104** are symmetrical so that the gas separators **110***b*, **110***a* for the cathode and anode respectively are identical in size, construction, volume, and their ability to separate gas bubbles from the fluid. In addition, both sides may require a dissolved ozone sensor, such as either two UV sensors **108** or one sensor that can measure two separate fluid paths, or a single sensor that has a series of isolation valves that can redirect either side of the system through the sensor will provide the system with the ability to monitor ozone gas in either the cathode recirculation path **118** or the anode recirculation path **116**. The potential to measure ozone gas in both paths simultaneously or alternating measurement from one side of the system to the other could provide added self-diagnostics. By monitoring both sides a decision can be made to maintain the anode as the anode or if ozone levels are acceptably low (less than 0.2 ppm or lower or undetectable) the system could reverse polarity. The polarity to the cell may be changed through an H-bridge and provides output flow from whichever side of the system is producing ozone. Another benefit to monitoring ozone levels in both the anode and cathode is to monitor for gas crossover. Ozone in the cathode recirculation path **118** could indicate early signs of cell membrane perforation or loss of fluid and or gas seals. This type of self-diagnostic may help to both mitigate safety concerns as well as alert the end users prior to a loss of functionality or performance.

[0063] The need to switch system polarity may come from a need to maintain fluid levels in the catholyte and two important system characteristics related to reliability. During operation water molecules are pulled through the membrane **212** via electro-osmosis. Overtime the catholyte separator may increase in its fluid level. Without a drain or reason to discharge from the cathode side of the system the cathode separator will fill up and eventually need to be drained. By switching the overall system polarity daily, the small increase in fluid level from a day of usage will be easily managed. The reliability requirements related to polarity switching stem from the electrolytic cells long-term performance objectives and the need to maintain the cleanliness of the water in the catholyte without the need for special startup or shutdown process steps. The membrane degradation that occurs from the interaction of ozone and other oxidative species (HO, H2O2, H3O . . .) can be distributed over both sides of the cell extending the life of each membrane. Furthermore, the catholyte may be exchanged daily and each side of the system may be ozonated preventing stagnant water and eliminating the possibility for microbial contamination.

[0064] There are conventional optical methods for detecting the level of dissolved ozone in water taking advantage of the ultraviolet light absorbance of ozone. However, changes in the mechanics and optical path (i.e., debris, aging of the UV source) may require an offset correction. By implementing a daily polarity change to the system the previous days catholyte water, water with dissolved hydrogen, can be used for zeroing out any sensor offsets making a correction without the variable concentration of an absorbing constituent in the water.

[0065] Turning now to FIG. **2**, an exploded view of a manifold compatible electrolytic ozone cell **104** (manifold compatible EO cell) is shown. The assembly contains an interfacial seal **202** to create a fluid seal between the EO cell **104** and the surface of a fluidic manifold. The top plate **204** and bottom plate **216** are joined to provide a rigid housing and to form the inner cavities that surround the inner components (i.e., contact plates, electrodes, membranes . . .). The top and bottom plate direct water flow to and from the electrode pair **210**. Separate water paths are formed by assembling all the components such that catholyte (cathode recirculation path **118**) side of the electrolytic ozone cell **104** prevents water and gas from mixing or crossing over to the anolyte side (anode recirculation path **116**) of the EO cell and vice versa. The top and bottom plate also define the cross-sectional area of the fluid path creating the necessary flow velocity to strip bubbles from the electrode and membrane surface and carry them away from the EO cell as they are formed. The tolerance compressor **206** provides both an inner seal to form the top side fluidic cavity and seals off the electrical contact area, however it also manages the tolerance stack up from the internal assembly by compressing and changing its overall thickness. The tolerance compressor **206** also produces and maintains a clamping force on the electrode assembly, namely the two Ti contact plates **208**, two electrodes **210**, and one or more and desirably, two or more proton exchange membranes **212**. Two membranes may improve life and may prevent mechanical shear stress from damaging the membrane. Further, two membranes may tend to slide, but the BDD electrode may grip said two electrodes. The inner bottom gasket/seal **214** seals the bottom plates to form the opposite side fluidic cavity. The inner bottom gasket/seal **214** also gathers the two electrodes **210** and two proton exchange membranes **212** into its inner rectangular opening presenting them orthogonally to the upper and lower contact plate **208**. The tolerance compressor **206** and/or the inner bottom gasket/seal **214** seal off the surface of the contact plates **208** to create a dry electrical contact zone on the small tab **220** or electrical contact zone of the contact plates. This electrical contact zone can be accessed through the top plates by spring loaded electrical contacts (e.g., pogo pins) so that the contact plates can provide electrical current to the electrodes during electrolysis. Both the tolerance compressor **206** and the inner bottom gasket/seal **214** create a seal with the top plate and bottom plate to prevent water and gas from leaking out of the seam between in the assembly. The assembly screws **218** secure the top and bottom plates and generate the forces necessary to compress the tolerance compressor **206** and inner bottom gasket/seal **214** to force the electrodes tightly onto the proton exchange membranes and secure the top and bottom plates together.

[0066] Turning now to FIG. **3**, an image of the inner components of a single electrode pair manifold compatible electrolytic cell is shown in different orientations.

[0067] FIG. **4** shows an example photograph of the inside surface of the Boron Doped Diamond coated electrodes and Proton exchange membranes after 77 hours of an example test operation which produced 6 ppm ozone using a closed loop control (~12V and 0.3 A). "White damage" (created by visible light diffusion that may be due to blistering in the membrane) on the ozone side can be seen. Blistering may create zones in the membrane that are less conductive. By putting the cell back together with the same electrodes and membranes to test if the seal would hold, and running the test for 18.6 hours, it was found that the cell did not show cross over.

[0068] FIG. **5** is an image of a proton exchange membrane **212** after several 100 hours of operation demonstrating how the electrodes move closer to each other as the proton exchange membrane thins under the constant degradation that occurs during electrolysis. This thinning is managed by the tolerance compressor which maintains an adequate clamping force on the electrode pair during the life of the EO cell. Taking up tolerances for the material stack up to be either at maximum material or least material conditions is another important aspect of the tolerance compressor. Each assembly may achieve a minimal normal force (in the y direction of FIG. **2**) to produce an acceptable EO cell impedance. Too low of a clamping force only use a portion of the electrode surface, reducing the EO cells' ability to produce ozone. Too high of a clamping force caused by a maximum material condition may result in electrode damage, membrane damage, or over compression on seals resulting in a loss of fluid pathway. The tolerance compressor **206** addresses all these concerns. The material may be inert to ozone and may provide adequate compression over a large range of compression, for example 2 to 10%, or 2 to 30%, or 10 to 50%, or 2 to 50% of its thickness. This high level of compression and material compatibility can be achieved by materials such as a closed-cell ethylene propylene diene monomer (EPDM) foam.

[0069] FIG. **6** highlights the location and thickness of the tolerance compressor in a cross-sectional view **602** which also demonstrates how the tolerance compressor applies force to the internal stack-up of components after the top and bottom plates reduce its thickness during the assembly process. The compressible layer **604** (or tolerance compressor **206**) accounts for any thinning of the proton exchange membrane **212** such that compressive forces on at least the electrode-membrane-electrode stack **606** are maintained. That is, the proton exchange membrane **212** may experience thinning from the mechanical seating into the surface of boron doped diamond coating as well as the loss of membrane material from membrane degradation. The membrane **212** may also swell from initial hydration from a dry state. Thus, the tolerance compressor **206** compresses or expands to accommodate the shrinking or the swelling. Further, taking up tolerances for the material stack up to be either at maximum material or least material conditions is another important aspect of the tolerance compressor. Each assembly may achieve a minimal normal force to produce an acceptable EO cell impedance. Too low of a clamping force may only use a portion of the electrode surface, reducing the EO cells' ability to produce ozone. Too high of a clamping force caused by a maximum material condition "MMC" (all parts are at their maximum tolerance and the assembly is tight) may result in electrode damage, membrane damage, or over compression on seals resulting in a loss of fluid pathway. The tolerance compressor **206** addresses all these concerns.

[0070] FIG. **7** shows an embodiment of a scaler equipped with an aqueous ozone generator. In order to maintain the size of the scaler a fluidic manifold may be envisioned. The manifold enables a scaler without dramatically changing its footprint or size to produce aqueous ozone. A fluidic system capable of emptying water from a consumable is added. A pressurized system (e.g., 17 to 25 psi, typically 22 psi) is generated. Said water is converted via electrolysis into ozonated water via a closed loop control circuit equipped with a UV absorbance sensor to maintain ozone concentration, and this water is delivered to an ultrasonic handpiece **106**.

[0071] FIG. **8**, shows a transparent housing view, demonstrating a manifold assembly **804** integrated into an ultrasonic scaler housing.

[0072] FIG. **9** provides a top perspective **902** and a bottom perspective **904** view of the manifold assembly. The manifold assembly **804** may include 5 core submodules. The manifold compatible electrolytic ozone cell **104** may in an exemplary embodiment provide a coplanar seal (e.g., interfacial seals **202** disposed in the x-z plane of top plate as shown in FIG. **2**) departing from fluidic fittings (e.g., push to connect or barbed fluid fitting). The electrolytic ozone cell **104** may be designed for volume production installation. It is characterized as having a simplified electrode, contact scheme, and seal arrangement. The interfacial seal **202** and low-profile design (relatively short height in the y-direction of FIG. **2** compared to conventional designs) make it compact and able to directly support existing industrial ultrasonic scaler system designs and manifold integration. For example, should the assembly to be welded, it may be 4-6 mm thick instead of, for example, 12-25 mm thick to accommodate threads and fittings and other assembly hardware. Inline catalyst **906** (O3 removal) may destroy ozone gas, by converting it from ozone to oxygen (O2) so that excess ozone gas can be vented from the manifold. The Inline catalyst O3 removal may be designed as an integrated body into the manifold assembly **804**. The design may provide underside access to support serviceability as catalyst used to destroy ozone could be a serviceable element. A UV sensor **108** may utilize the absorbance of ultraviolet light by ozone to quantify the ozone concentration. The UV sensor **108** may have a simplified tolerance stack, thermal stability and reduced size compared to conventional UV sensors to support the integration into the aqueous ozone ultrasonic scaler system **100**, and its optics pathway may be shared across both anode and cathode pathways to reduce the number of fluidic valves required to support intermittent (e.g., daily) polarity switching. As each other day the catholyte side is changed over to the anolyte side and the uv sensor **108** may be required to monitor the water recirculating in the anolyte side of the manifold. A magnet float level sensing **908** may be designed to monitor the fluid levels in the gas separators. The gas separators **110***a*, **110***b* may maintain a fluid level during operation, thus, the float provides a stable indicator of the water level which can then be tracked via an array of Hall effect sensors. The sensitivity of the magnetic float level sensing provides enough fidelity for real-time flowrate monitoring, providing the system and user with information the volume of water being dispensed per unit time (e.g., 20 ml/min). The magnet float level sensing **908** may be configured to be mechanically independent to eliminate the dependence on optical or capacitive sensors that may see sloshing, droplets, or bubbles in their level sensing. A reduced size pressure relieve valve **910** (PRV), compared to conventional sizes may provide stable low hysteresis regulation of the system pressure (i.e., 15 to 30 psi, more typically 19 to 21 psi, 19.5 to 22.5 psi range). Thus, the "reduced" size of the PRV **910** is intended to support the small footprint of the aqueous ozone ultrasonic scaler system **100**.

[0073] FIG. **10** provides a top perspective **902** of an example manifold assembly **804** showing that the electrical connections for the electrolytic ozone cell **104** can be installed after the electrolytic ozone cell **104** has been mounted, secured, and sealed off with the manifold.

[0074] FIG. **11**, illustrates a bottom perspective **904** of an example manifold assembly **804**. This figure depicts the low profile of the electrolytic ozone cell **104** and a housing (top and bottom plates) of the electrolytic cell which is configured to be coupled to the manifold assembly **804** of an aqueous ozone ultrasonic scaler system **100** such that it has a flush coplanar interface with the manifold surface **1102** (in the lengthwise/horizontal direction of the assembly **804**, i.e., x-z plane as shown in FIG. **11**).

[0075] FIG. **12**, depicts a bottom perspective **904** view of an exemplary manifold assembly **804** showing an example electrolytic ozone cell **104** and a location of the cell in the manifold assembly **804**. In the figure, details of the cell's interfacial seals **202** are depicted as an O-ring interface. However, a single gasket may be fashioned to replace the four 0-rings and provide a gas tight and fluidic tight seal between the electrolytic ozone cell **104** and the manifold surface.

[0076] FIG. **13** shows a cross sectional view **1304** of manifold assembly **804** showing electrolytic ozone cell electrical connections.

[0077] Spring loaded pogo pins **1302** extend down through the manifold and reach into the cell **104** to engage the contact plates (Ti contact plate **208**) electrically. The pogo pins **1302** may generate the normal force required to produce a reliable electrical connection with the contact plates (e.g., Titanium contact plates), while also taking up variation in dimensional tolerances as they collapse during their compression between the EO cell contact plate and a pogo support structure on the opposite side of the manifold. In an illustrative embodiment, the pogo pins are terminated into a printed circuit board that is connected either directly or via a small board-to-board cable harness back to the main control board. The pogo pins deliver the electrical current that drives the electrolytic reaction in the EO cell. Wires may be soldered to the pogo pins **1302** at solder locations **1306** and pogo pins **1302** may make contact with the Ti contact plates **208** at top contact **1308** and bottom contact **1310**.

[0078] FIG. **14**, illustrates an alternative embodiment with the electrolytic ozone cell **104** being built with two pairs of electrodes. The electrolytic ozone cell **104** can be configured with one, two, or more electrode pairs. An advantage of having two pairs of BDD electrodes **210**, each independently controlled such that each electrode has a contact plate, and a separate electrical connection is that the fluid flows through both electrode pairs, so that they are plumbed in series by channels within the manifold. Alternatively, a cell design could be developed that had a single fluid inlet and a single fluid outlet, so that the cell provides the fluidic interconnection between the two pairs of electrodes. Electrically however they have separate constant current drive circuits. This enables a main controller to turn on either one or both pairs. Both pairs of electrodes may be used in order to build up the concentration of ozone quickly, after the system has been off or in a prolonged sleep mode (overnight, between patients, or over lunch). The current to each pair can also be independently controlled so that each pair can receive a range of currents from no current, to 150 ma, or from 100 to 1000 ma (typically 250 ma per cell). Each pair can be run independently so that one pair of electrodes can be off while the other is used to maintain the ozone concentration (0.2 to 22 ppm, typically 6 ppm).

[0079] FIG. **15**, shows a cross-sectional area of an electrolytic ozone cell **104** showing a bubble clearance gap **1502** above electrode. The dimensions of the fluidic path about the electrode are shown, with the bubble clearance gap **1502** being linked to the overall system requirements, namely recirculation flow rates (volume per unit time), rate of ozone production, output flow rate from the system, and the ozone setpoint. Between the BDD electrode **210** and the bottom plate **216**, a fluid path is formed by the thickness and inner profile of the Ti contact plate **208**. This fluid path controls the velocity of the water moving over the face of the BDD electrode **210**. Too slow of a fluid flow (e.g., large gap and low flow rate) may result in bubbles becoming entrapped and reducing the efficiency of the electrolytic ozone cell **104** as fresh water cannot reach the triple phase boundary. A similar fluid path is formed on the opposite side of this pair of electrodes; however, the tolerance compressor forms this fluid path. In an alternative design an additional member or outer layer may be included in the tolerance compressor to provide a rig uniform wall comparable to the bottom housing surface. Maintaining a fully symmetrical design directly supports polarity switching, such that either side of the electrode pair can become the cathode or anode.

[0080] FIG. **16**, depicts an electrolytic ozone cell **104** footprint with symmetrical fluidic and electrical connections. A symmetrical footprint may eliminate the need to orient the cell with the manifold. This may directly support the ease of manufacturing the assembly and serviceability. Because the cell is fully symmetrically, both electrically and fluidically, there may be no initial orientation requirements. The flow path into the cell and the exit path from the cell as shown may have no variation in geometry and the electrical polarity of each pair of electrodes may be intended to be reversed on a periodic (e.g., daily) basis to improve reliability of the cell and to flush the catholyte every other day. A fully symmetrical cell design may eliminate the need for mechanical keying features and the possibility of damaging the coplanar interface by securing the cell in the wrong orientation. Assume that the cell of FIG. **16** has two sides, side A and side B, the footprint may be configured to have a side A electrical contact **1602**, a side A outlet **1604**, a side B outlet **1606**, a side B electrical contact **1608**, a side B inlet **1610**, and a side A inlet **1612**.

[0081] FIG. **17**, shows an electrode **1702** with example dimensions, having a tab **1704** to provide direct electrical contact, depicting a configuration that may eliminate a need for a separate contact plate. Thus, the contact plate has been integrated into the electrode. The electrode may be made from a titanium sheet, its profile may be stamped, laser cut, or etched. Or the electrode may be formed by metal injection molding or powder medal sintering. This titanium substrate may then be coated with boron doped diamonds using vapor deposition. The coating is conductive and can cover the entire substrate or alternatively the tab could be masked prior to coating to provide a titanium surface for the electrical connection. This tabbed electrode eliminates the needs for a contact plate and reduces part count and simplifies assembly steps.

[0082] Having described the apparatus, reference will now be made to FIG. **18**, which shows a block diagram of a computer system **1800** that may be employed in accordance with at least some of the illustrative embodiments herein. Although various embodiments may be described herein in terms of this exemplary computer system **1800**, after reading this description, it may become apparent to a person skilled in the relevant art(s) how to implement the disclosure using other computer systems and/or architectures.

[0083] In one example embodiment herein, at least some components of the aqueous ozone ultrasonic scaler system **100** in which the electrolytic ozone cell **104** is disposed may form or be included in the computer system **1800** of FIG. **18**. The computer system **1800** includes at least one computer processor **1806**. The computer processor **1806** may include, for example, a central processing unit (CPU), a multiple processing unit, an application-specific integrated circuit ("ASIC"), a field programmable gate array ("FPGA"), or the like. The computer processor **1806** may be connected to a communication infrastructure **1802** (e.g., a communications bus, a cross-over bar device, a network). In an illustrative embodiment herein, the computer processor **1806** includes a CPU that that controls the electrolytic ozone cell **106** and timing of the ozone formation process.

[0084] The display interface **1808** (or other interface such) forwards text, video graphics, and other data from the communication infrastructure **1802** (or from a frame buffer (not shown)) for display on display unit **1814**. For example, the display interface **1808** may include a video card with a graphics processing unit or may provide an operator with an interface for controlling the apparatus.

[0085] The computer system **1800** may also include an input unit **1810** that may be used, along with the display unit **1814** by an operator of the computer system **1800** to send information to the computer processor **1806**, such as information to control the operation of the electrolytic ozone cell **104**. The input unit **1810** may include for example, a touchscreen monitor. In one example, the display unit **1814**, the input unit **1810**, and the computer processor **1806** may collectively form a user interface.

[0086] One or more steps of providing ozonated water to an ultrasonic scaler handpiece may be stored on a non-transitory storage device in the form of computer-readable program instructions. To execute a procedure, the computer processor **1806** loads the appropriate instructions, as stored on storage device, into memory and then executes the loaded instructions.

[0087] The computer system **1800** may further comprise a main memory **1804**, which may be a random-access memory ("RAM"), and also may include a secondary memory **1818**. The secondary memory **1818** may include, for example, a hard disk drive **1820** and/or a removable-storage drive **1822** (e.g., a floppy disk drive, a magnetic tape drive, an optical disk drive, a flash memory drive, and the like). The removable-storage drive **1822** reads from and/or writes to a removable storage unit **1826** in a well-known manner. The removable storage unit **1826** may be, for example, a floppy disk, a magnetic tape, an optical disk, a flash memory device, and the like, which may be written to and read from by the removable-storage drive **1822**. The removable storage unit **1826** may include a non-transitory computer-readable storage medium storing computer-executable software instructions and/or data.

[0088] In further illustrative embodiments, the secondary memory **1818** may include other computer-readable media storing computer-executable programs or other instructions to be loaded into the computer system **1800**. Such devices may include removable storage unit **1828** and an interface **1824** (e.g., a program cartridge and a cartridge interface); a removable memory chip (e.g., an erasable programmable read-only memory ("EPROM") or a programmable read-only memory ("PROM")) and an associated memory socket; and other removable storage units **1828** and interfaces **1824**

that allow software and data to be transferred from the removable storage unit **1828** to other parts of the computer system **1800**.

[0089] The computer system **1800** may also include a communications interface **1812** that enables software and data to be transferred between the computer system **1800** and external devices. Such an interface may include a modem, a network interface (e.g., an Ethernet card or an IEEE 802.11 wireless LAN interface), a communications port (e.g., a Universal Serial Bus ("USB") port or a FireWire® port), a Personal Computer Memory Card International Association ("PCMCIA") interface, Bluetooth®, and the like. Software and data transferred via the communications interface **1812** may be in the form of signals, which may be electronic, electromagnetic, optical or another type of signal that may be capable of being transmitted and/or received by the communications interface **1812**. Signals may be provided to the communications interface **1812** via a communications path **1816** (e.g., a channel). The communications path **1816** carries signals and may be implemented using wire or cable, fiber optics, a telephone line, a cellular link, a radio-frequency ("RF") link, or the like. The communications interface **1812** may be used to transfer software or data or other information between the computer system **1800** and a remote server or cloud-based storage (not shown).

[0090] One or more computer programs or computer control logic may be stored in the main memory **1804** and/or the secondary memory **1818**. The computer programs may also be received via the communications interface **1812**. The computer programs include computer-executable instructions which, when executed by the computer processor **1806**, cause the computer system **1800** to perform the methods as described hereinafter. Accordingly, the computer programs may control the computer system **1800** and other components of the aqueous ozone ultrasonic scaler system **100**.

[0091] In another embodiment, the software may be stored in a non-transitory computer-readable storage medium and loaded into the main memory **1804** and/or the secondary memory **1818** using the removable-storage drive **1822**, hard disk drive **1820**, and/or the communications interface **1812**. Control logic (software), when executed by the computer processor **1806**, causes the computer system **1800**, and more generally the apparatus, to perform the some or all of the methods described herein.

[0092] Lastly, in another example embodiment hardware components such as ASICs, FPGAs, and the like, may be used to carry out the functionality described herein. Implementation of such a hardware arrangement so as to perform the functions described herein will be apparent to persons skilled in the relevant art(s) in view of this description.

1. An electrolytic ozone cell comprising:
a housing including:
  an interfacial seal;
  a top plate; and
  bottom plate; and
an internal compartment that includes at least:
  a pair of contact plates;
  a tolerance compressor that compresses an electrode-membrane-electrode stack which includes a pair of electrodes and at least one proton exchange membrane,
wherein the electrode-membrane-electrode stack is disposed between the pair of contact plates and the tolerance compressor is configured to alter the dimensions of the tolerance compressor responsive to thinning of the proton exchange membrane, in order to maintain compressive forces on at least the electrode-membrane-electrode stack.

2. The electrolytic ozone cell of claim **1**, wherein a housing of the electrolytic cell is configured to be coupled to a manifold assembly of an aqueous ozone ultrasonic scaler Systems such that it has a flush coplanar interface with the manifold surface.

3. The electrolytic ozone cell of claim **1**, wherein the pair of contact plates are titanium (Ti) contact plates.

4. The electrolytic ozone cell of claim **1**, wherein the pair of electrodes are boron dope diamond (BDD) electrodes.

5. The electrolytic ozone cell of claim **1**, wherein an electrode of the pair of electrodes is a perforated silicon plate with a boron doped diamond coating.

6. The electrolytic ozone cell of claim **5**, wherein the boron doped diamond coating has a thickness of between 1.00 nm up and 15 μm.

7. The electrolytic ozone cell of claim **1**, wherein the pair of electrodes and the proton exchange membrane form an electrode-membrane-electrode stack and the tolerance compressor provides compression for the electrode-membrane-electrode stack over a range of between 2 to 50% of the thickness of the tolerance compressor.

8. The electrolytic ozone cell of claim **1**, wherein the tolerance compressor is inert to ozone.

9. The electrolytic ozone cell of claim **1**, wherein the tolerance compressor is made from a closed-cell ethylene propylene diene monomer (EPDM) foam material.

10. The electrolytic ozone cell of claim **1**, wherein a path for water flow is based on a thickness and inner profile of a contact plate of the pair of contact plates.

11. The electrolytic ozone cell of claim **1**, wherein the electrolytic ozone cell comprises more than one pair of pair of electrodes.

12. The electrolytic ozone cell of claim **1**, wherein an electrical contact zone of a contact plate of the pair of contact plates is accessed through the top plate by a spring-loaded electrical contact so that the contact plate provides electrical current to an electrode of the pair of electrodes.

13. The electrolytic ozone cell of claim **1**, wherein a contact plate and an electrode are integrated together to form an electrode unit that provide provides direct electrical contact for a spring-loaded electrical contact.

14. The electrolytic ozone cell of claim **1**, wherein the cell is configured to control a velocity of water that flows over an area of bubble formation along triple phase boundaries (TPB) formed by an electrode-water-membrane intersection.

15. The electrolytic ozone cell of claim **12**, wherein the electrolytic ozone cell further includes an inner bottom gasket wherein the inner bottom gasket and the tolerance compressor seal off one or more surfaces of the pair of contact plates to create one or more dry electrical contact zones on the tabs of the pair of contact plates.

17. The electrolytic ozone cell of claim **1**, wherein the electrode-membrane-electrode stack includes one or more pairs of electrodes in the same cell.

18. The electrolytic ozone cell of claim **17**, wherein the one or more pairs are each independently controlled.

19. An apparatus comprising:
a water supply for delivering water to an electrolytic ozone cell;
a gas separator disposed in a recirculation loop of a fluid pathway that also contains the electrolytic cell; and
the electrolytic ozone cell;
wherein the electrolytic ozone cell further comprises:
a housing including:
 an interfacial seal;
 a top plate; and
 bottom plate; and
an internal compartment that includes at least:
 a pair of contact plates;
 a tolerance compressor that compresses an electrode-membrane-electrode stack which includes a pair of electrodes and at least one proton exchange membrane,
wherein the electrode-membrane-electrode stack is disposed between the pair of contact plates and the tolerance compressor is configured to alter the dimensions of the tolerance compressor responsive to thinning of the proton exchange membrane, in order to maintain compressive forces on at least the electrode-membrane-electrode stack.

20. (canceled)

21. (canceled)

22. (canceled)

23. (canceled)

24. A computer system comprising:
a processor configured to control an operation of an electrolytic ozone cell; and
the electrolytic ozone cell;
wherein the electrolytic ozone cell further comprises:
a housing including:
 an interfacial seal;
 a top plate; and
 bottom plate; and
an internal compartment that includes at least:
 a pair of contact plates;
 a tolerance compressor that compresses an electrode-membrane-electrode stack which includes a pair of electrodes and at least one proton exchange membrane,
wherein the electrode-membrane-electrode stack is disposed between the pair of contact plates and the tolerance compressor is configured to alter the dimensions of the tolerance compressor responsive to thinning of the proton exchange membrane, in order to maintain compressive forces on at least the electrode-membrane-electrode stack.

25. (canceled)

26. (canceled)

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