

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
24 January 2008 (24.01.2008)

PCT

(10) International Publication Number  
**WO 2008/010108 A2**

(51) International Patent Classification: Not classified

(21) International Application Number:  
PCT/IB2007/051997

(22) International Filing Date: 27 May 2007 (27.05.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
11/450,042 9 June 2006 (09.06.2006) US  
2,579,737 27 February 2007 (27.02.2007) CA

(71) Applicant (for all designated States except US): **KUZO HOLDING INC.** [—/BB]; Worthing Corporate Centre, Worthing Main Road, Christ Church, BB15008 (BB).

(71) Applicant and

(72) Inventor: **DAVIDSON, Nehemia** [IL/IL]; 32/3 Granit Street, 48541 Rosh-haayin (IL).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH,

CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

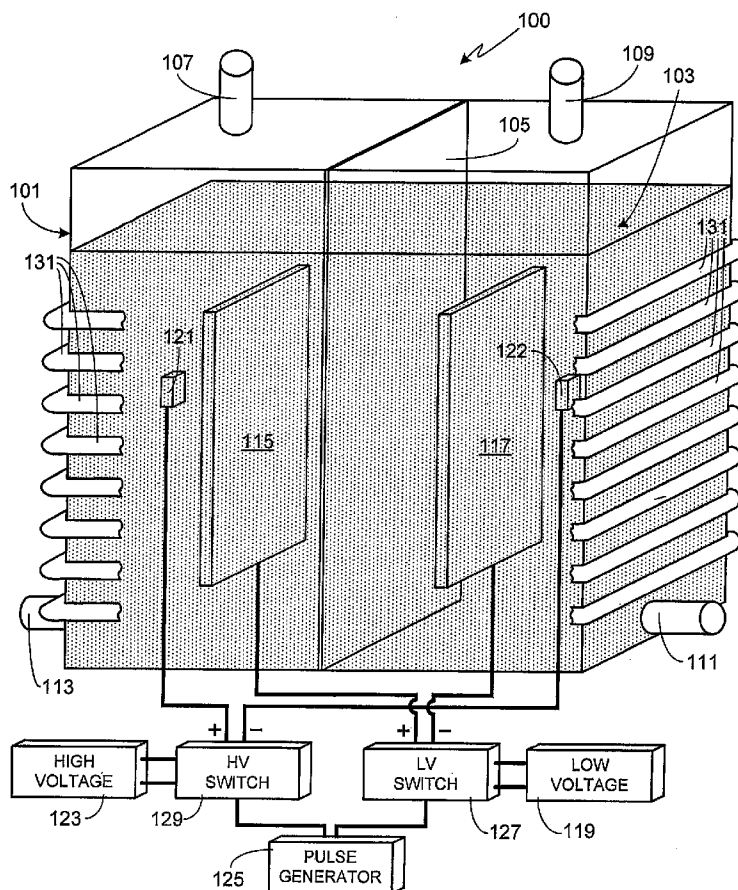
(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: DUAL VOLTAGE ELECTROLYSIS APPARATUS AND METHOD OF USING SAME



(57) Abstract: An electrolysis system (100) and method of using same is provided. In addition to an electrolysis tank (101) and a membrane (105) separating the tank into two regions, the system includes at least one pair of low voltage electrodes (115/117) comprised of a first material and at least one pair of high voltage electrodes (121/122) comprised of the same, or different, material. The separation distance between the cathode and anode of each pair of high voltage electrodes is greater than the separation distance between the cathode and anode of each pair of low voltage electrodes with the low voltage electrodes of each pair of low voltage electrodes being located between the pair, or pairs, of high voltage electrodes. The low voltage applied to the low voltage electrodes and the high voltage applied to the high voltage electrodes is pulsed with the pulses occurring simultaneously.

WO 2008/010108 A2

## Description

### Dual Voltage Electrolysis Apparatus and Method of Using Same

#### Technical Field

- [1] The present invention relates generally to electrolysis systems and, more particularly, to a high efficiency electrolysis system and methods of using same.

#### Background Art

- [2] Fossil fuels, in particular oil, coal and natural gas, represent the primary sources of energy in today's world. Unfortunately in a world of rapidly increasing energy needs, dependence on any energy source of finite size and limited regional availability has dire consequences for the world's economy. In particular, as a country's need for energy increases, so does its vulnerability to disruption in the supply of that energy source. Additionally, as fossil fuels are the largest single source of carbon dioxide emissions, a greenhouse gas, continued reliance on such fuels can be expected to lead to continued global warming. Accordingly it is imperative that alternative, clean and renewable energy sources be developed that can replace fossil fuels.
- [3] Hydrogen-based fuel is currently one of the leading contenders to replace fossil fuel. There are a number of techniques that can be used to produce hydrogen, although the primary technique is by steam reforming natural gas. In this process thermal energy is used to react natural gas with steam, creating hydrogen and carbon dioxide. This process is well developed, but due to its reliance on fossil fuels and the release of carbon dioxide during production, it does not alleviate the need for fossil fuels nor does it lower the environmental impact of its use over that of traditional fossil fuels. Other, less developed hydrogen producing techniques include (i) biomass fermentation in which methane fermentation of high moisture content biomass creates fuel gas, a small portion of which is hydrogen; (ii) biological water splitting in which certain photosynthetic microbes produce hydrogen from water during their metabolic activities; (iii) photoelectrochemical processes using either soluble metal complexes as a catalyst or semiconducting electrodes in a photochemical cell; (iv) thermochemical water splitting using chemicals such as bromine or iodine, assisted by heat, to split water molecules; (v) thermolysis in which concentrated solar energy is used to generate temperatures high enough to split methane into hydrogen and carbon; and (vi) electrolysis.
- [4] Electrolysis as a means of producing hydrogen has been known and used for over 80 years. In general, electrolysis of water uses two electrodes separated by an ion conducting electrolyte. During the process hydrogen is produced at the cathode and oxygen is produced at the anode, the two reaction areas separated by an ion conducting diaphragm. Electricity is required to drive the process. An alternative to conventional electrolysis is high temperature electrolysis, also known as steam electrolysis. This

process uses heat, for example produced by a solar concentrator, as a portion of the energy required to cause the needed reaction. Although lowering the electrical consumption of the process is desirable, this process has proven difficult to implement due to the tendency of the hydrogen and oxygen to recombine at the technique's high operating temperatures.

- [5] A high temperature heat source, for example a geothermal source, can also be used as a replacement for fossil fuel. In such systems the heat source raises the temperature of water sufficiently to produce steam, the steam driving a turbine generator which, in turn, produces electricity. Alternately the heat source can raise the temperature of a liquid that has a lower boiling temperature than water, such as isopentane, which can also be used to drive a turbine generator. Alternately the heat source can be used as a fossil fuel replacement for non-electrical applications, such as heating buildings.

## **Disclosure of Invention**

### **Technical Problem**

- [6] Although a variety of alternatives to fossil fuels in addition to hydrogen and geothermal sources have been devised, to date none of them have proven acceptable for a variety of reasons ranging from cost to environmental impact to availability. Accordingly, what is needed is a new energy source, or a more efficient form of a current alternative energy source, that can effectively replace fossil fuels without requiring an overly complex distribution system.

### **Technical Solution**

- [7] The present invention provides an electrolysis system and method of using same. In addition to an electrolysis tank and a membrane separating the tank into two regions, the system includes at least one pair of low voltage electrodes comprised of a first material and at least one pair of high voltage electrodes comprised of the same, or different, material. Each pair of electrodes includes a cathode and an anode with the separation distance between the cathode and anode of each pair of high voltage electrodes being greater than the separation distance between the cathode and anode of each pair of low voltage electrodes. Additionally both low voltage electrodes of each pair of low voltage electrodes are located between the pair, or pairs, of high voltage electrodes. The low voltage applied to the low voltage electrodes is pulsed as is the high voltage applied to the high voltage electrodes, the low voltage pulses and the high voltage pulses being timed to occur simultaneously. Preferably the liquid within the tank is comprised of one or more of; water, deuterated water, tritiated water, semiheavy water, heavy oxygen water, and/or any other water containing an isotope of either hydrogen or oxygen.
- [8] Preferably the low and high voltage pulses occur at a frequency between 50 Hz and 7

kHz and with a pulse duration of between 0.1 and 75 percent of the time period defined by the frequency, and more preferably with a pulse duration of between 1 and 50 percent of the time period defined by the frequency. Preferably the ratio of the high voltage to the low voltage is at least 5:1, more preferably within the range of 5:1 to 100:1, still more preferably within the range of 5:1 to 33:1, and still more preferably within the range of 5:1 to 20:1. Preferably the low voltage is between 3 and 1500 volts, more preferably between 12 and 750 volts. Preferably the high voltage is between 50 volts and 50 kilovolts, more preferably between 100 volts and 5 kilovolts. The low voltage electrodes and the high voltage electrodes are fabricated from any of a variety of materials, although preferably the electrode material is selected from the group consisting of steel, nickel, copper, iron, stainless steel, cobalt, manganese, zinc, titanium, platinum, palladium, and alloys thereof. The low voltage electrodes and the high voltage electrodes can utilize any of a variety of surface shapes, with each pair of electrodes, i.e., the cathode and anode of each pair, being either positioned parallel to one another or not parallel to one another.

- [9] In at least one embodiment of the invention, the concentration of electrolyte in the liquid is between 0.05 and 10 percent by weight. In at least one other embodiment of the invention, the concentration of electrolyte in the liquid is between 0.05 and 2.0 percent by weight. In yet at least one other embodiment of the invention, the concentration of electrolyte in the liquid is between 0.05 and 0.1 percent by weight.

### **Description of Drawings**

- [10] Fig. 1 is an illustration of an exemplary embodiment of the invention;
- [11] Fig. 2 is an illustration of an alternate exemplary embodiment utilizing multiple pairs of low voltage electrodes;
- [12] Fig. 3 is an illustration of an alternate exemplary embodiment utilizing multiple pairs of high voltage electrodes;
- [13] Fig. 4 is an illustration of an alternate exemplary embodiment utilizing multiple pairs of low voltage electrodes and multiple pairs of high voltage electrodes;
- [14] Fig. 5 is an illustration of an alternate exemplary embodiment utilizing a vertical cylindrical tank;
- [15] Fig. 6 is an illustration of an alternate exemplary embodiment utilizing a horizontal cylindrical tank;
- [16] Fig. 7 is an illustration of an alternate exemplary embodiment utilizing a horizontal cylindrical tank and a separation membrane running lengthwise in the tank;
- [17] Fig. 8 is an illustration of one mode of operation;
- [18] Fig. 9 is an illustration of an alternate mode of operation that includes initial process optimization steps;
- [19] Fig. 10 is an illustration of an alternate, and preferred, mode of operation in which

the process undergoes continuous optimization;

[20] Fig. 11 is a block diagram illustrating the preferred optimization control system; and

[21] Fig. 12 is a top, cross-sectional view of the embodiment shown in Fig. 1.

### **Best Mode**

[22] Fig. 1 is an illustration of an exemplary embodiment of the invention. Electrolysis system 100 includes a tank 101 comprised of a non-conductive material, the size of the tank depending primarily upon the desired output of the system as well as the dimensions of the electrodes contained within the tank. Although tank 101 is shown as having a rectangular shape, it will be appreciated that the invention is not so limited and that tank 101 can utilize other shapes, for example cylindrical, square, irregularly-shaped, etc. Tank 101 is substantially filled with liquid 103. In at least one preferred embodiment, liquid 103 is comprised of water with an electrolyte, the electrolyte being either an acid electrolyte or a base electrolyte. Exemplary electrolytes include potassium hydroxide and sodium hydroxide. The term 'water' as used herein refers to water (H<sub>2</sub>O), deuterated water (deuterium oxide or D<sub>2</sub>O), tritiated water (tritium oxide or T<sub>2</sub>O), semiheavy water (HDO), heavy oxygen water (H<sub>2</sub><sup>18</sup>O or H<sub>2</sub><sup>17</sup>O) or any other water containing an isotope of either hydrogen or oxygen, either singly or in any combination thereof (for example, a combination of H<sub>2</sub>O and D<sub>2</sub>O).

[23] A typical electrolysis system used to decompose water into hydrogen and oxygen gases utilizes relatively high concentrations of electrolyte. The present invention, however, has been found to work best with relatively low electrolyte concentrations, thereby maintaining a relatively high water resistivity (e.g., typically on the order of 1 to 2 megohms). Note that this resistivity is based on the initial resistance of the water since typically after the system has been operating for a while (for example, on the order of 5 to 6 hours), the resistivity of the water may drop. Preferably the concentration of electrolyte is in the range of 0.05 percent to 10 percent by weight, more preferably the concentration of electrolyte is in the range of 0.05 percent to 2.0 percent by weight, and still more preferably the concentration of electrolyte is in the range of 0.1 percent to 0.2 percent by weight.

[24] Separating tank 101 into two regions is a membrane 105. Membrane 105 permits ion/electron exchange between the two regions of tank 101 while keeping separate the oxygen and hydrogen bubbles produced during electrolysis. Maintaining separate hydrogen and oxygen gas regions is important not only as a means of allowing the collection of pure hydrogen gas and pure oxygen gas, but also as a means of minimizing the risk of explosions due to the inadvertent recombination of the two gases. Exemplary materials for membrane 105 include, but are not limited to, polypropylene, tetrafluoroethylene, asbestos, etc. In at least one preferred embodiment, membrane 105 is 25 microns thick and comprised of polypropylene.

- [25] As noted herein, the present system is capable of generating considerable heat. Accordingly, system components such as tank 101 and membrane 105 that are expected to be subjected to the heat generated by the system must be fabricated from suitable materials and designed to indefinitely accommodate the intended operating temperatures as well as the internal tank pressure. For example, in at least one preferred embodiment the system is designed to operate at a temperature of approximately 90° C at standard pressure. In an alternate exemplary embodiment, the system is designed to operate at elevated temperatures (e.g., 100° C to 150° C) and at sufficient pressure to prevent boiling of liquid 103. In yet another alternate exemplary embodiment, the system is designed to operate at even higher temperatures (e.g., 200° C to 250° C) and higher pressures (e.g., sufficient to prevent boiling). Accordingly, it will be understood that the choice of materials (e.g., for tank 101 and membrane 105) and the design of the system (e.g., tank wall thicknesses, fittings, etc.) will vary, depending upon the intended system operational parameters (primarily temperature and pressure).
- [26] Other standard features of electrolysis tank 101 are gas outlets 107 and 109. As hydrogen gas is produced at the cathode and oxygen gas is produced at the anode, in the exemplary embodiment shown in Fig. 1 oxygen gas will exit tank 101 through outlet 107 while hydrogen gas will exit through outlet 109. Replenishment of liquid 103 is preferably through a separate conduit, for example conduit 111. In at least one embodiment of the invention, another conduit 113 is used to remove liquid 103 from the system. If desired, a single conduit can be used for both liquid removal and replenishment.
- [27] In at least one embodiment in which electrolysis system 100 is used to produce large quantities of hydrogen, the system utilizing system 100 also includes means for either storing the produced gases, e.g., hydrogen storage tanks, or means for delivering the produced gas to the point of consumption, e.g., pipes and valves, as well as flow gauges, pressure gauges, gas compressors, gas driers, gas purifiers, etc.
- [28] The electrolysis system of the invention uses two types of electrodes, each type of electrode being comprised of one or more electrode pairs with each electrode pair including at least one cathode (i.e., a cathode coupled electrode) and at least one anode (i.e., an anode coupled electrode). All cathodes, regardless of the type, are kept in one region of tank 101 while all anodes, regardless of the type, are kept in the other tank region, the two tank regions separated by membrane 105. In the embodiment illustrated in Fig. 1, each type of electrode includes a single pair of electrodes.
- [29] The first pair of electrodes, electrodes 115/117, are coupled to a low voltage source 119. The second set of electrodes, electrodes 121/122, are coupled to a high voltage source 123. As described and illustrated, voltage source 119 is referred to and labeled as a 'low' voltage source not because of the absolute voltage produced by the source,

but because the output of voltage source 119 is maintained at a lower output voltage than the output of voltage source 123. Preferably and as shown, the individual electrodes of each pair of electrodes are parallel to one another; i.e., the face of electrode 115 is parallel to the face of electrode 117 and the face of electrode 121 is parallel to the face of electrode 122.

[30] In a preferred embodiment, electrodes 115/117 and electrodes 121/122 are comprised of titanium. In another preferred embodiment, electrodes 115/117 and electrodes 121/122 are comprised of stainless steel. It should be appreciated, however, that other materials can be used and that the same material does not have to be used for both the low and high voltage electrodes. In addition to titanium and stainless steel, other exemplary materials that can be used for the low voltage and high voltage electrode pairs include, but are not limited to, copper, iron, cobalt, steel, manganese, zinc, nickel, platinum, palladium, and alloys of these materials. Preferably the area of the face of electrode 115, and similarly the area of the face of electrode 117, covers a large percentage of the cross-sectional area of tank 101, typically on the order of at least 40 percent of the cross-sectional area of tank 101, and often between approximately 70 percent and 90 percent of the cross-sectional area of tank 101. Although the separation distance between electrode pairs is dependent upon a variety of factors (e.g., tank size, voltage/current, etc.), in at least one preferred embodiment the separation of the low voltage electrodes (e.g., electrodes 115 and 117) is between 3 millimeters and 15 centimeters, and more preferably on the order of 10 to 12 centimeters.

[31] Electrodes 121/122 are positioned outside of electrodes 115/117. In other words, the separation distance between electrodes 121 and 122 is greater than the separation distance between electrodes 115 and 117 and both low voltage electrodes are positioned between the high voltage electrodes. Although the high voltage electrodes (e.g., electrodes 121/122) may be larger, smaller or the same size as the low voltage electrodes (e.g., electrodes 115/117), typically the surface area of the high voltage electrodes is less than that of the low voltage electrodes, and more typically the surface area of the high voltage electrodes is much less than that of the low voltage electrodes. In one exemplary preferred embodiment, the surface area of electrodes 121/122 is approximately 0.2 percent the surface area of electrodes 115/117 while in another exemplary preferred embodiment the surface area of electrodes 121/122 is approximately 2 percent the surface area of electrodes 115/117.

[32] As previously noted, the voltage applied to high voltage electrode pair 121/122 is greater than that applied to low voltage electrodes 115/117. Preferably the ratio of the high voltage to the low voltage is at least 5:1, more preferably the ratio is between 5:1 and 100:1, still more preferably the ratio is between 5:1 and 33:1, and even still more preferably the ratio is between 5:1 and 20:1. Typically the high voltage generated by

source 123 is within the range of 50 volts to 50 kilovolts, and preferably within the range of 100 volts to 5 kilovolts. Typically the low voltage generated by source 119 is within the range of 3 volts to 1500 volts, and preferably within the range of 12 volts to 750 volts. Rather than continually apply voltage to the electrodes, sources 119 and 123 are pulsed, preferably at a frequency of between 50 Hz and 7 kHz with a pulse width (i.e., pulse duration) of between 0.1 and 75 percent of the time period defined by the selected frequency, and more preferably with a pulse width of between 1 and 50 percent of the time period defined by the selected frequency. Thus, for example, for a frequency of 150 Hz, the pulse duration is preferably in the range of 6.7 microseconds to 5 milliseconds, and more preferably in the range of 67 microseconds to 3.3 milliseconds. Alternately, for example, for a frequency of 1 kHz, the pulse duration is preferably in the range of 1 microsecond to 0.75 milliseconds, and more preferably in the range of 10 microseconds to 0.5 milliseconds. The frequency and/or pulse duration can be changed during system operation, thus allowing the system output efficiency to be continually optimized. Voltage is simultaneously applied to electrodes 121/122 from source 123 and electrodes 115/117 from source 119. In other words, the pulses applied to electrodes 121/122 coincide with the pulses applied to electrodes 115/117. Although voltage sources 119 and 123 can include internal means for pulsing the respective outputs from each source, preferably an external pulse generator 125 controls a pair of switches, i.e., a low voltage switch 127 and a high voltage switch 129 which, in turn, control the output of voltage sources 119 and 123 as shown, and as described above.

- [33] As described herein, the electrolysis process of the invention generates considerable heat. It will be appreciated that if the system is allowed to become too hot for a given pressure, the fluid within tank 101 will begin to boil. Additionally, various system components may be susceptible to heat damage. Although the system can be turned off and allowed to cool when the temperature exceeds a preset value, for example using a control system coupled to a thermocouple or other heat monitor which triggers the control system when the system (or tank fluid) exceeds the preset value, this is not a preferred approach due to the inherent inefficiency of stopping the process, allowing the system to cool, and then restarting the system. A more efficient, and preferred, approach uses means which actively cool the system to maintain the temperature within an acceptable range. In at least one preferred embodiment, the cooling system does not allow the temperature to exceed 90° C. Although it will be appreciated that the invention is not limited to a specific type of cooling system or a specific implementation of the cooling system, in at least one embodiment tank 101 is surrounded by coolant conduit 131, portions of which are shown in Figs. 1-7. Within coolant conduit 131 is a heat transfer medium, for example water. Coolant conduit 131 can either

surround a portion of the electrolysis tank as shown, or be contained within the electrolysis tank, or be integrated within the walls of the electrolysis tank. The coolant pump and refrigeration system is not shown in the figures as cooling systems are well known by those of skill in the art.

- [34] As will be appreciated by those of skill in the art, there are numerous minor variations of the system described herein and shown in Fig. 1 that will function substantially the same as the disclosed system. As previously noted, alternate configurations can utilize differently sized/shaped tanks, different electrolytic solutions, and a variety of different electrode configurations and materials. Additionally the system can utilize a range of input powers, frequencies and pulse widths (i.e., pulse duration). In general, the exact configuration depends upon the desired output as well as available space and power. Figs. 2-7 illustrate a few alternate configurations, including the use of multiple pairs of low voltage electrodes (i.e., Fig. 2), multiple pairs of high voltage electrodes (i.e., Fig. 3), multiple pairs of low voltage and high voltage electrodes (e.g., Fig. 4), vertical cylindrical tanks (e.g., Fig. 5), and horizontal cylindrical tanks (e.g., Figs. 6 and 7).
- [35] Fig. 2 illustrates an alternate embodiment of the system shown in Fig. 1, the alternate configuration replacing low voltage electrode 115 with four low voltage electrodes 201-204 and replacing low voltage electrode 117 with four low voltage electrodes 205-208.
- [36] Fig. 3 illustrates an alternate embodiment of the system shown in Fig. 1, the alternate configuration replacing high voltage electrode 121 with three high voltage electrodes 301-303 and replacing high voltage electrode 122 with three high voltage electrodes 305-307.
- [37] Fig. 4 illustrates an alternate embodiment of the system shown in Fig. 1, the alternate configuration replacing low voltage electrode 115 with four low voltage electrodes 401-404, replacing low voltage electrode 117 with four low voltage electrodes 405-408, replacing high voltage electrode 121 with three high voltage electrodes 409-411 and replacing high voltage electrode 122 with three high voltage electrodes 413-415.
- [38] Fig. 5 illustrates an alternate embodiment of the system shown in Fig. 1, the alternate configuration replacing tank 101 with a vertically configured cylindrical tank 501.
- [39] Fig. 6 illustrates an alternate embodiment of the system shown in Fig. 1, the alternate configuration replacing tank 101 with a horizontally configured cylindrical tank 601, replacing membrane 105 with an appropriately shaped membrane 603, replacing low voltage electrodes 115/117 with shaped low voltage electrodes 605/606 and replacing high voltage electrodes 121/122 with shaped high voltage electrodes 607/608.
- [40] Fig. 7 illustrates an alternate embodiment of the system shown in Fig. 1, the alternate

configuration replacing tank 101 with a horizontally configured cylindrical tank 701 which utilizes a lengthwise membrane 703. Additionally, low voltage electrodes 115/117 are replaced with low voltage electrodes 705/706 and high voltage electrodes 121/122 are replaced with high voltage electrodes 707/708.

[41] As previously noted, the present electrolysis system can be used to generate hydrogen gas and oxygen gas. The system can also be used to generate electricity, for example by placing a load across the low voltage electrodes. The primary benefit of the present configuration, however, is as a means of generating heat.

[42] In one set of tests that illustrate the heat generation capabilities of the electrolysis system of the invention, a cylindrical chamber configured as shown in Fig. 7 was used. The tank was 125 centimeters long with an inside diameter of 44 centimeters and an outside diameter of 50 centimeters. The tank contained 175 liters of water, the water including a potassium hydroxide (KOH) electrolyte at a concentration of 0.1 % by weight. The low voltage electrodes, i.e., electrodes 705/706 in Fig. 7, were 75 centimeters by 30 centimeters by 0.5 centimeters and had a separation distance of approximately 10 centimeters. The high voltage electrodes, i.e., electrodes 707/708 in Fig. 7, were 3 centimeters by 2.5 centimeters by 0.5 centimeters and had a separation distance of approximately 32 centimeters. Both sets of electrodes were comprised of titanium. The pulse frequency was maintained at 150 Hz and the pulse duration was initially set to 260 microseconds and gradually lowered to 180 microseconds during the course of a 4 hour run. The low voltage supply was set to 50 volts, drawing a current of between 5.5 and 7.65 amps, and the high voltage supply was set to 910 volts, drawing a current of between 2.15 and 2.48 amps. The initial temperature was 28° C and monitored continuously with a pair of thermocouples, one in each side of the tank. After conclusion of the 4 hour run, the temperature of the tank fluid had increased to 67° C.

[43] The inventor has found a direct correlation between the efficiency of the electrolysis apparatus of the invention and electrode size, the power supplied to the electrodes, and the pulse frequency/duration. For example, another test was performed similar to the above test, but replacing the high voltage electrodes with larger electrodes, the larger electrodes measuring 9.5 centimeters by 5 centimeters by 0.5 centimeters. As a result, the new high voltage electrodes provided approximately 6.3 times the surface area of the previous high voltage electrodes. The larger electrodes, still operating at a voltage of 910 volts, drew a current of between 1.73 and 1.9 amps. The low voltage supply was again set at 50 volts, in this run the low voltage electrodes drawing between 0.6 and 1.25 amps. Although the pulse frequency was still maintained at 150 Hz, the pulse duration was lowered from an initial setting of 60 microseconds to 15 microseconds. All other operating parameters were the same as in the previous test. In this test, during

the course of a 5 hour run, the temperature of the tank fluid increased from 28° C to 69° C. Given the shorter pulses and the lower current, this test with the larger high voltage electrodes exhibited an efficiency approximately 8 times that exhibited in the previous test.

- [44] It should be understood that the present invention can be operated in a number of modes, the primary differences between modes being the desired primary system output (i.e., heat, hydrogen or electricity) and the degree of process optimization used during operation. For example, Fig. 8 illustrates one method of operation requiring minimal optimization. As illustrated, initially the electrolysis tank is filled with water (step 801). The level of water in the tank preferably just covers the top of the electrodes although the process can also be run with even more water filling the tank. The electrolyte can either be mixed into the water prior to filling the tank or after the tank is filled. The frequency of the pulse generator is then set (step 803) as well as the pulse duration (step 805), the pulse generator controlling the output pulse frequency/duration for both the high voltage supply and the low voltage supply. The initial voltage settings for the low voltage power supply (e.g., source 119) and the high voltage power supply (e.g., source 123) are also set (step 807), although it will be appreciated that the order of set-up is clearly not critical to the electrolysis process. Once set-up is complete, electrolysis is initiated (step 809) and continues (step 811) until process termination is desired (step 813).
- [45] The above sequence of processing steps works best once the operational parameters have been optimized for a specific system configuration since the system configuration will impact the efficiency of the process and therefore the system output. Exemplary system configuration parameters that affect the optimal electrolysis settings include tank size, quantity of water, electrolyte composition, electrolyte concentration, pressure, electrode size, electrode composition, electrode shape, electrode separation, low voltage setting, high voltage setting, pulse frequency and pulse duration.
- [46] Fig. 9 illustrates an alternate procedure appropriate, for example, for use with new, untested system configurations, the approach providing optimization steps. Initially the tank is filled (step 901) and initial settings for pulse frequency (step 903), pulse duration (step 905), high voltage supply output (step 907) and low voltage supply output (step 909) are made. Typically the initial settings are based on previous settings that have been optimized for a similarly configured system. For example, assuming that the new configuration was the same as a previous configuration except for the composition of the electrodes, a reasonable initial set-up would be the optimized set-up from the previous configuration.
- [47] After the initial set-up is completed, electrolysis is initiated (step 911) and the output of the system is monitored (step 913). Thus, for example, assuming that the system is

to be optimized for heat production, the rate of temperature increase would be monitored in step 913. System optimization can begin immediately or the system can be allowed to run for an initial period of time (step 915) prior to optimization. As step 915 is optional, it is shown in phantom. The initial period of operation can be based on achieving a predetermined temperature or a different criteria can be used. Alternately the initial period of time can simply be a predetermined time period, for example 30 minutes.

[48] After the initial time period is exceeded, assuming that the selected approach uses step 915, the system output is monitored (step 917) while optimizing one or more of the operational parameters. Although the order of parameter optimization is not critical, in at least one preferred embodiment the first parameter to be optimized is pulse duration (step 919) followed by the optimization of the pulse frequency (step 920). Then the voltage of the high voltage supply is optimized (step 921) followed by the optimization of the output voltage of the low voltage supply (step 922). In this embodiment after optimization is complete, based on system performance, the electrolysis process is allowed to continue (step 923) without further optimization until the process is halted, step 925. In another, and preferred, alternative approach illustrated in Fig. 10, optimization steps 919-922 are performed continuously throughout the electrolysis process until electrolysis is suspended. Alternately a subset of steps 919-922 can be performed continuously throughout the electrolysis process.

[49] The optimization process described relative to Figs. 9 and 10 can be performed manually. In the preferred embodiment, however, the system and the optimization of the system are controlled via computer as illustrated in the block diagram of Fig. 11. As shown, computer 1101 receives system performance data from monitor 1103. For example, monitor 1103 can monitor the temperature of the fluid within the tank, thus allowing absolute temperature and the rate of temperature change to be monitored and/or determined. Using this information computer 1101 varies the output of high voltage source 1105, the output of low voltage source 1107 and the frequency and pulse duration generated by pulse generator 1109 in order to optimize the output of the system as previously described.

[50] As previously described, preferably the electrodes are flat and arranged such that the flat electrodes faces are parallel to one another. This is illustrated in Fig. 12 which is a top, cross-sectional view of the electrode configuration of the system illustrated in Fig. 1. It should be appreciated that such a configuration is not a requirement of the invention. For example, some or all of the electrodes can utilize curved surfaces and/or be arranged in a non-parallel geometry.

## Claims

- [1] An electrolysis system comprising:  
an electrolysis tank;  
a membrane separating said electrolysis tank into a first region and a second region, wherein said membrane restricts hydrogen gas flow and oxygen gas flow between said first and second regions;  
at least one pair of low voltage electrodes contained within said electrolysis tank, said at least one pair of low voltage electrodes comprised of a first material, wherein each pair of said at least one pair of low voltage electrodes includes an anode and a cathode;  
at least one pair of high voltage electrodes contained within said electrolysis tank, said at least one pair of high voltage electrodes comprised of a second material, wherein each pair of said at least one pair of high voltage electrodes includes an anode and a cathode, wherein said anodes of said at least one pair of low voltage electrodes and said anodes of said at least one pair of high voltage electrodes are contained within said first region, wherein said cathodes of said at least one pair of low voltage electrodes and said cathodes of said at least one pair of high voltage electrodes are contained within said second region, and wherein a first separation distance corresponding to the distance between the high voltage electrodes of each pair of said at least one pair of high voltage electrodes is greater than a second separation distance corresponding to the distance between the low voltage electrodes of each pair of said at least one pair of low voltage electrodes;  
a low voltage source with a first output voltage electrically connected to said at least one pair of low voltage electrodes;  
a high voltage source with a second output voltage electrically connected to said at least one pair of high voltage electrodes, wherein said second output voltage is higher than said first output voltage; and  
means for simultaneously pulsing both said low voltage source and said high voltage source voltage at a specific frequency and with a specific pulse duration.
- [2] The electrolysis system of claim 1, further comprising means for cooling said electrolysis system.
- [3] The electrolysis system of claim 2, wherein said cooling means is comprised of a conduit containing a heat transfer medium, wherein a portion of said conduit is in thermal communication with at least a portion of said electrolysis tank.
- [4] The electrolysis system of claim 3, wherein said portion of said conduit surrounds at least a portion of said electrolysis tank.

- [5] The electrolysis system of claim 3, wherein said portion of said conduit is contained within said electrolysis tank.
- [6] The electrolysis system of claim 3, wherein said portion of said conduit is integrated within a portion of a wall comprising said electrolysis tank.
- [7] The electrolysis system of claim 3, wherein said heat transfer medium is comprised of water.
- [8] The electrolysis system of claim 1, wherein said simultaneous pulsing means comprises a pulse generator coupled to said low voltage source and to said high voltage source.
- [9] The electrolysis system of claim 1, wherein said simultaneous pulsing means comprises a pulse generator coupled to a low voltage switch and coupled to a high voltage switch, wherein said low voltage switch is coupled to said low voltage source, and wherein said high voltage switch is coupled to said high voltage source.
- [10] The electrolysis system of claim 1, wherein said simultaneous pulsing means comprises a first internal pulse generator coupled to said low voltage source and a second internal pulse generator coupled to said high voltage source.
- [11] The electrolysis system of claim 1, wherein a ratio of said second output voltage to said first output voltage is at least 5 to 1.
- [12] The electrolysis system of claim 1, wherein a ratio of said second output voltage to said first output voltage is within the range of 5:1 to 100:1.
- [13] The electrolysis system of claim 1, wherein a ratio of said second output voltage to said first output voltage is within the range of 5:1 to 33:1.
- [14] The electrolysis system of claim 1, wherein a ratio of said second output voltage to said first output voltage is within the range of 5:1 to 20:1.
- [15] The electrolysis system of claim 1, further comprising a liquid within said electrolysis tank.
- [16] The electrolysis system of claim 15, wherein said liquid includes at least one of water, deuterated water, tritiated water, semiheavy water, heavy oxygen water, water containing an isotope of hydrogen, or water containing an isotope of oxygen.
- [17] The electrolysis system of claim 15, further comprising an electrolyte within said liquid, said electrolyte having a concentration of between 0.05 and 10.0 percent by weight.
- [18] The electrolysis system of claim 15, further comprising an electrolyte within said liquid, said electrolyte having a concentration of between 0.05 and 2.0 percent by weight.
- [19] The electrolysis system of claim 15, further comprising an electrolyte within said

liquid, said electrolyte having a concentration of between 0.1 and 0.2 percent by weight.

- [20] The electrolysis system of claim 1, wherein said first material is selected from the group consisting of steel, nickel, copper, iron, stainless steel, cobalt, manganese, zinc, titanium, platinum, palladium, and alloys of steel, nickel, copper, iron, stainless steel, cobalt, manganese, zinc, titanium, platinum, and palladium, and wherein said second material is selected from the group consisting of steel, nickel, copper, iron, stainless steel, cobalt, manganese, zinc, titanium, platinum, palladium, and alloys of steel, nickel, copper, iron, stainless steel, cobalt, manganese, zinc, titanium, platinum, and palladium.
- [21] The electrolysis system of claim 1, wherein said first output voltage is between 3 volts and 1500 volts and said second output voltage is between 50 volts and 50 kilovolts.
- [22] The electrolysis system of claim 1, wherein said first output voltage is between 12 volts and 750 volts and said second output voltage is between 100 volts and 5 kilovolts.
- [23] The electrolysis system of claim 1, wherein the electrodes of each pair of said at least one pair of low voltage electrodes are positioned parallel to one another.
- [24] The electrolysis system of claim 1, wherein the electrodes of each pair of said at least one pair of high voltage electrodes are positioned parallel to one another.
- [25] The electrolysis system of claim 1, wherein each low voltage electrode of said at least one pair of low voltage electrodes is curved.
- [26] The electrolysis system of claim 1, wherein each low voltage electrode of said at least one pair of low voltage electrodes is flat.
- [27] The electrolysis system of claim 1, wherein each high voltage electrode of said at least one pair of high voltage electrodes is curved.
- [28] The electrolysis system of claim 1, wherein each high voltage electrode of said at least one pair of high voltage electrodes is flat.
- [29] The electrolysis system of claim 1, wherein said specific frequency is between 50 Hz and 7 kHz.
- [30] The electrolysis system of claim 1, wherein said specific pulse duration is between 0.1 and 75 percent of a time period defined by said specific frequency.
- [31] The electrolysis system of claim 1, wherein said specific pulse duration is between 1 and 50 percent of a time period defined by said specific frequency.
- [32] A method of operating an electrolysis system comprising the steps of:  
positioning a membrane within an electrolysis tank, said membrane separating said electrolysis tank into a first region and a second region;  
filling said electrolysis tank with a liquid;

positioning at least one pair of low voltage electrodes within said electrolysis tank, wherein each pair of said at least one pair of low voltage electrodes includes at least one low voltage cathode electrode and at least one low voltage anode electrode, wherein said positioning step further comprises the steps of positioning each low voltage cathode electrode within said first region and positioning each low voltage anode electrode within said second region; positioning said at least one pair of high voltage electrodes within said electrolysis tank, wherein each pair of said at least one pair of high voltage electrodes includes at least one high voltage cathode electrode and at least one high voltage anode electrode, wherein said positioning step further comprises the steps of positioning each high voltage cathode electrode within said first region and positioning each high voltage anode electrode within said second region, and positioning each low voltage electrode of said at least one pair of low voltage electrodes between said at least one pair of high voltage electrodes; applying a low voltage to said at least one pair of low voltage electrodes, said low voltage applying step further comprising the step of pulsing said low voltage at a first frequency and with a first pulse duration; and applying a high voltage to said at least one pair of high voltage electrodes, said high voltage applying step further comprising the step of pulsing said high voltage at said first frequency and with said first pulse duration, and wherein said high voltage pulsing step is performed simultaneously with said low voltage pulsing step.

- [33] The method of claim 32, further comprising the step of selecting said liquid from the group consisting of water, deuterated water, tritiated water, semiheavy water, heavy oxygen water, water containing an isotope of hydrogen, or water containing an isotope of oxygen.
- [34] The method of claim 32, further comprising the step of adding an electrolyte to said liquid.
- [35] The method of claim 32, further comprising the step of selecting a concentration of said electrolyte to be within a range of 0.05 and 10.0 percent by weight.
- [36] The method of claim 32, further comprising the step of selecting a concentration of said electrolyte to be within a range of 0.05 and 2.0 percent by weight.
- [37] The method of claim 32, further comprising the step of selecting a concentration of said electrolyte to be within a range of 0.1 and 0.2 percent by weight.
- [38] The method of claim 32, further comprising the steps of:  
fabricating said at least one pair of low voltage electrodes from a first material;  
fabricating said at least one pair of high voltage electrodes from a second material; and

selecting said first material and said second material from the group consisting of steel, nickel, copper, iron, stainless steel, cobalt, manganese, zinc, titanium, platinum, palladium, and alloys of steel, nickel, copper, iron, stainless steel, cobalt, manganese, zinc, titanium, platinum, and palladium.

- [39] The method of claim 32, further comprising the steps of selecting said high voltage within the range of 50 volts to 50 kilovolts and selecting said low voltage within the range of 3 volts to 1500 volts.
- [40] The method of claim 32, further comprising the steps of selecting said high voltage within the range of 100 volts to 5 kilovolts and selecting said low voltage within the range of 12 volt to 750 volts.
- [41] The method of claim 32, further comprising the step of selecting said high voltage and said low voltage such that a ratio of said high voltage to said low voltage is at least 5 to 1.
- [42] The method of claim 32, further comprising the step of selecting said high voltage and said low voltage such that a ratio of said high voltage to said low voltage is within the range of 5:1 to 100:1.
- [43] The method of claim 32, further comprising the step of selecting said high voltage and said low voltage such that a ratio of said high voltage to said low voltage is within the range of 5:1 to 33:1.
- [44] The method of claim 32, further comprising the step of selecting said high voltage and said low voltage such that a ratio of said high voltage to said low voltage is within the range of 5:1 to 20:1.
- [45] The method of claim 32, further comprising the step of selecting said first frequency to be within the range of 50 Hz and 7 kHz.
- [46] The method of claim 32, further comprising the step of selecting said first pulse duration to be between 0.1 and 75 percent of a time period defined by said first frequency.
- [47] The method of claim 32, further comprising the step of selecting said first pulse duration to be between 1 and 50 percent of a time period defined by said first frequency.
- [48] The method of claim 32, further comprising the steps of:  
monitoring an output parameter of said electrolysis system; and  
optimizing an operating parameter of electrolysis system in response to said monitored output parameter.
- [49] The method of claim 48, further comprising the step of selecting said low voltage as said operating parameter.
- [50] The method of claim 48, further comprising the step of selecting said high voltage as said operating parameter.

- [51] The method of claim 48, further comprising the step of selecting said first frequency as said operating parameter.
- [52] The method of claim 48, further comprising the step of selecting said first pulse duration as said operating parameter.
- [53] The method of claim 48, further comprising the step of selecting heat generation as said output parameter.
- [54] The method of claim 48, further comprising the step of selecting hydrogen generation as said output parameter.
- [55] The method of claim 48, further comprising the step of operating said electrolysis system for an initial period of time prior to performing said optimizing step.
- [56] The method of claim 48, further comprising the step of achieving a preset value for said output parameter prior to performing said optimizing step.
- [57] The method of claim 48, wherein said optimizing step is performed repeatedly.
- [58] The method of claim 48, wherein said optimizing step is automated.

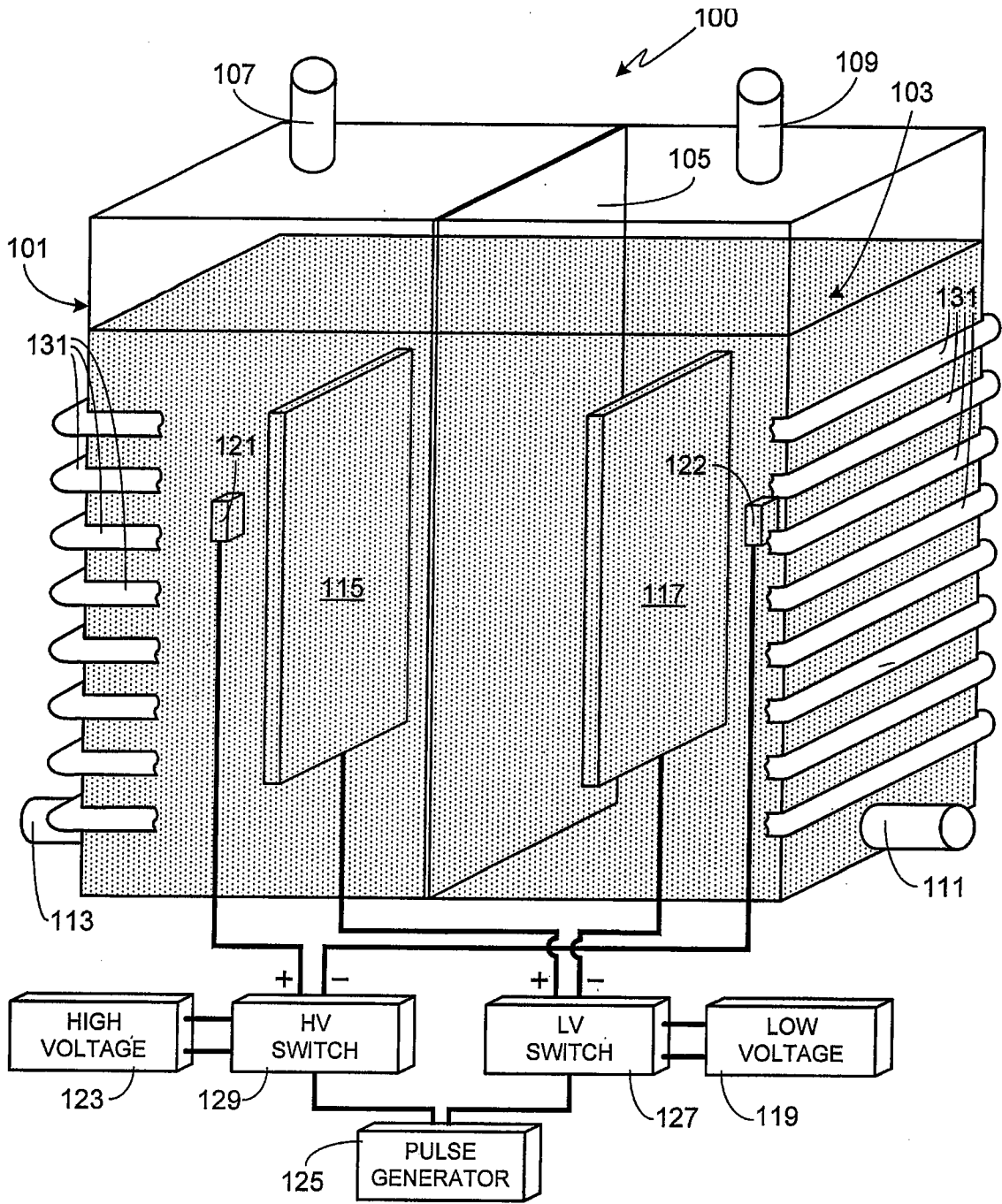


FIG. 1

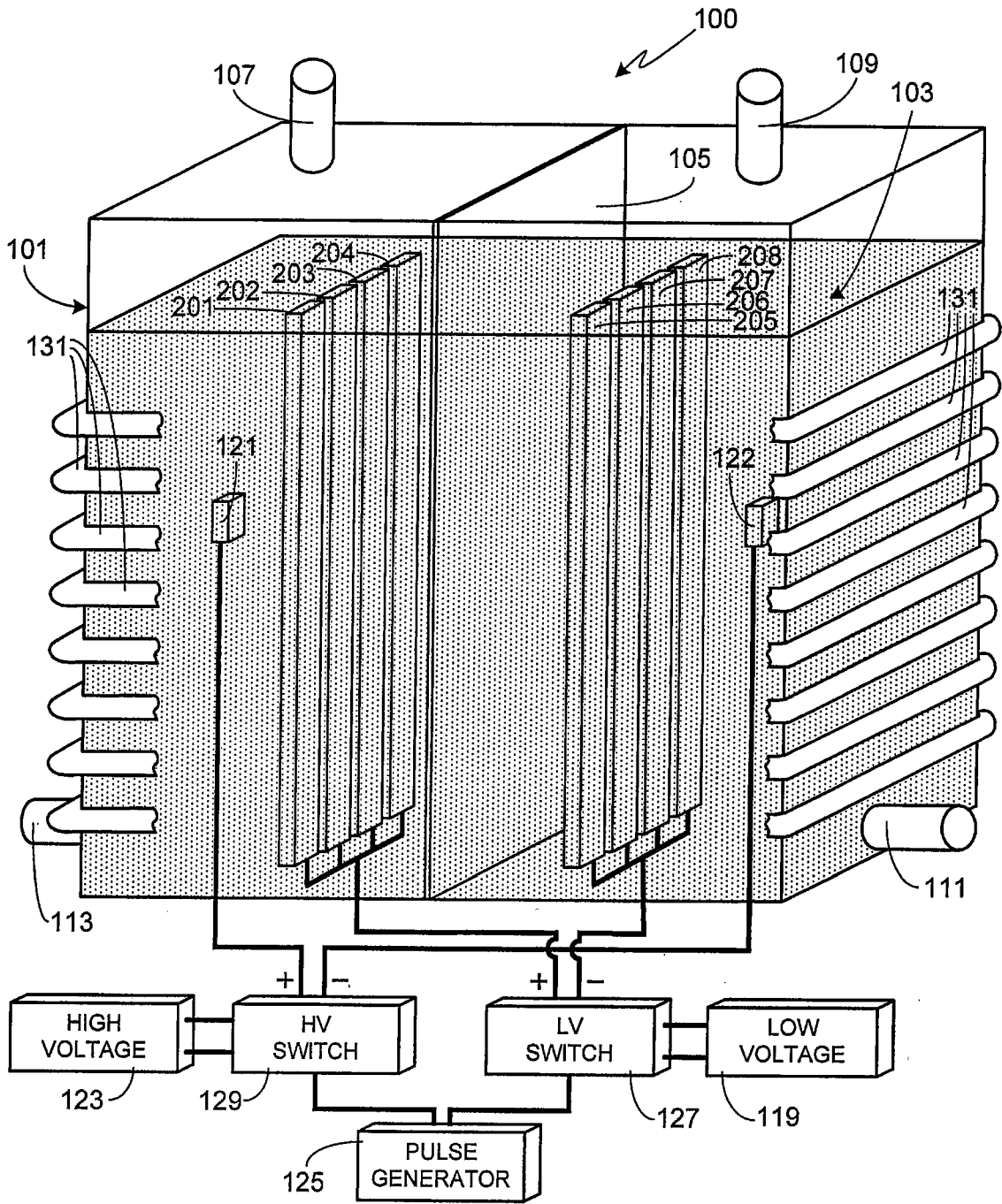


FIG. 2

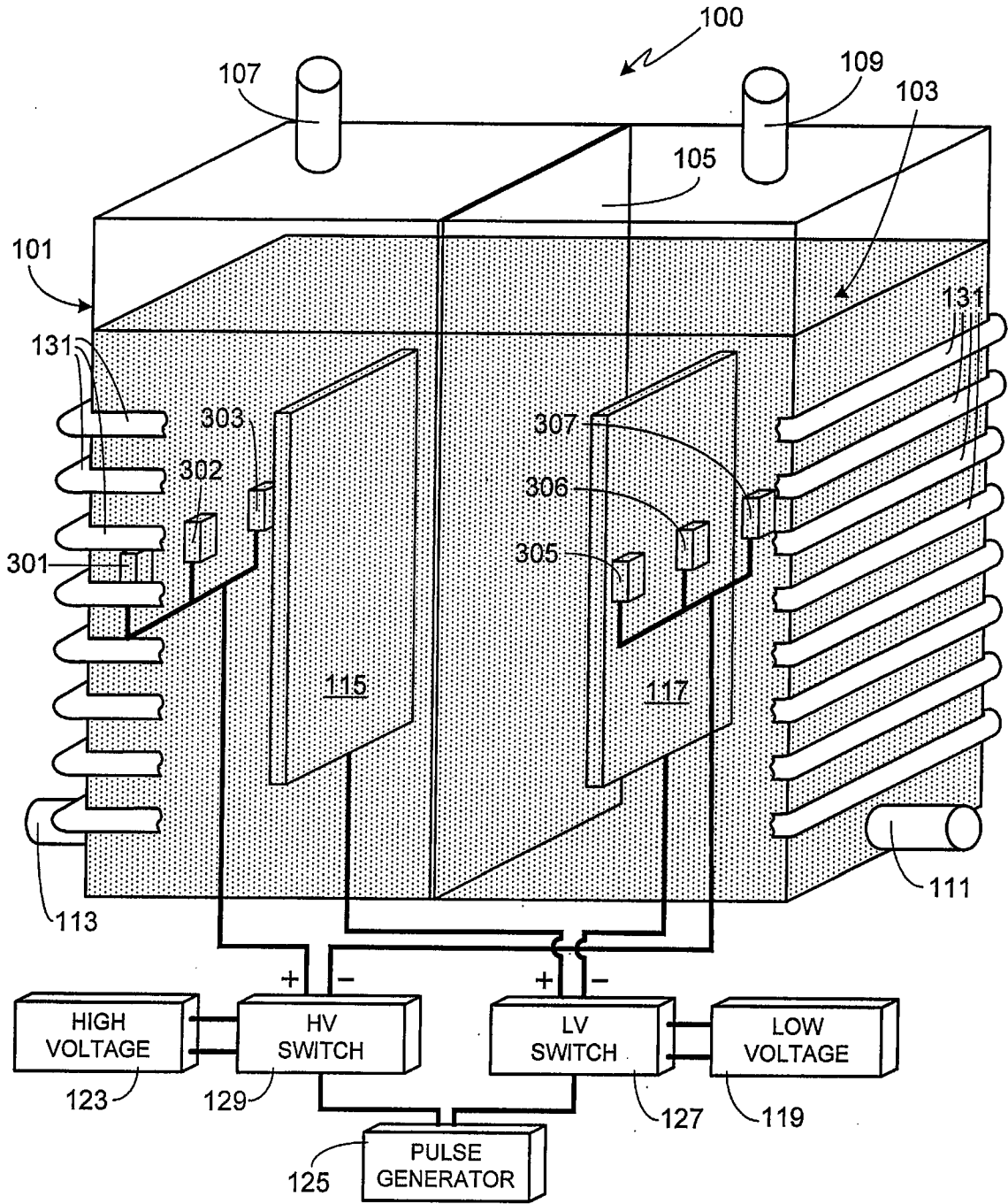


FIG. 3

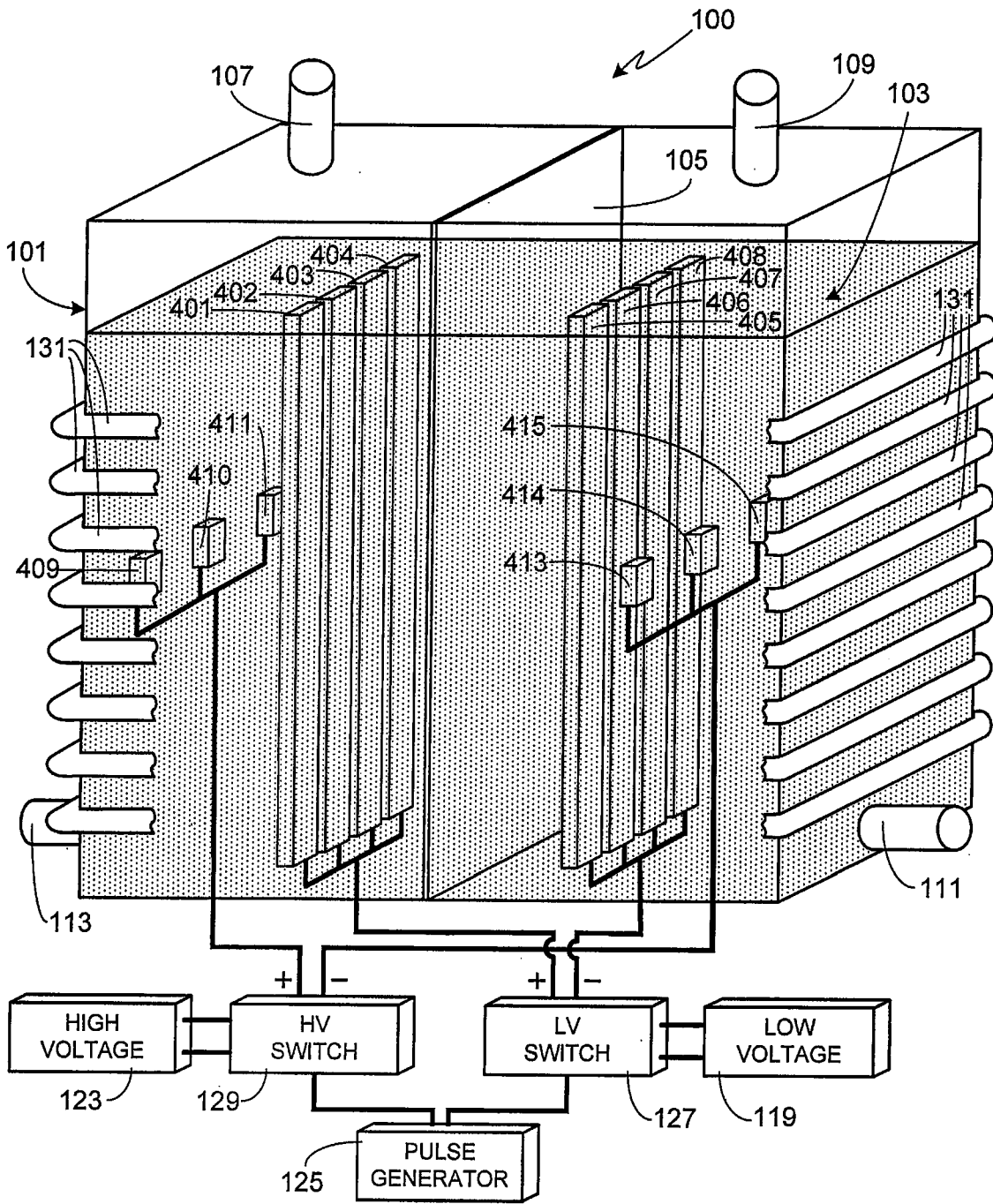


FIG. 4

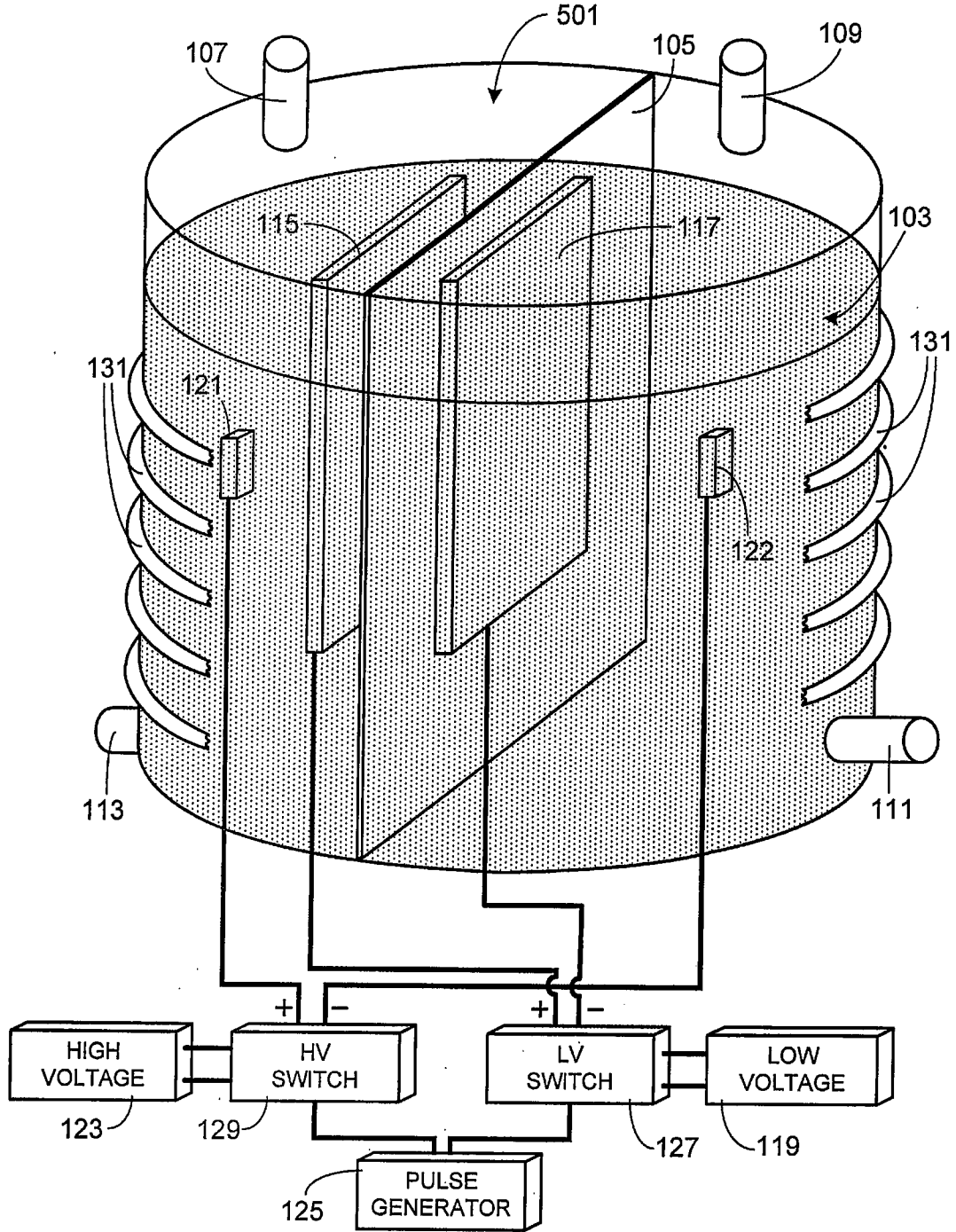


FIG. 5

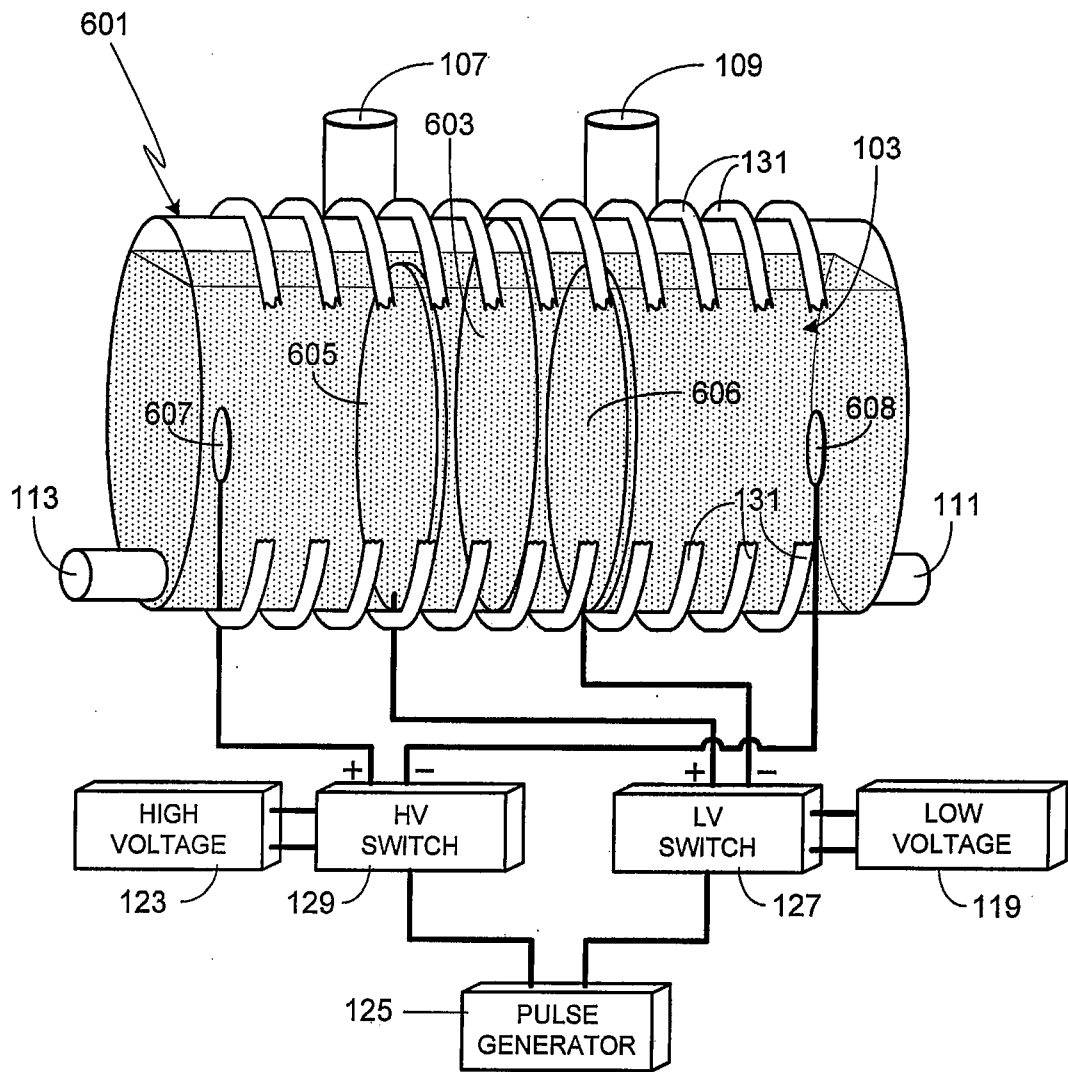


FIG. 6

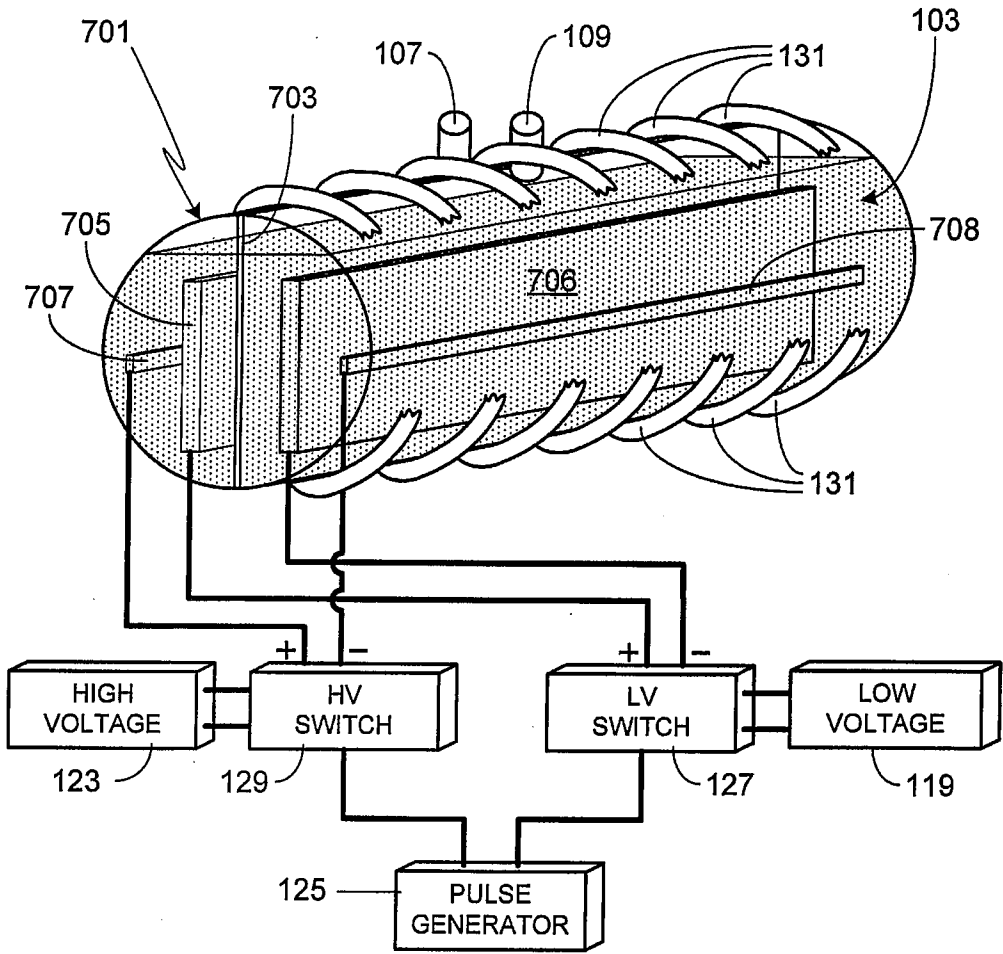


FIG. 7

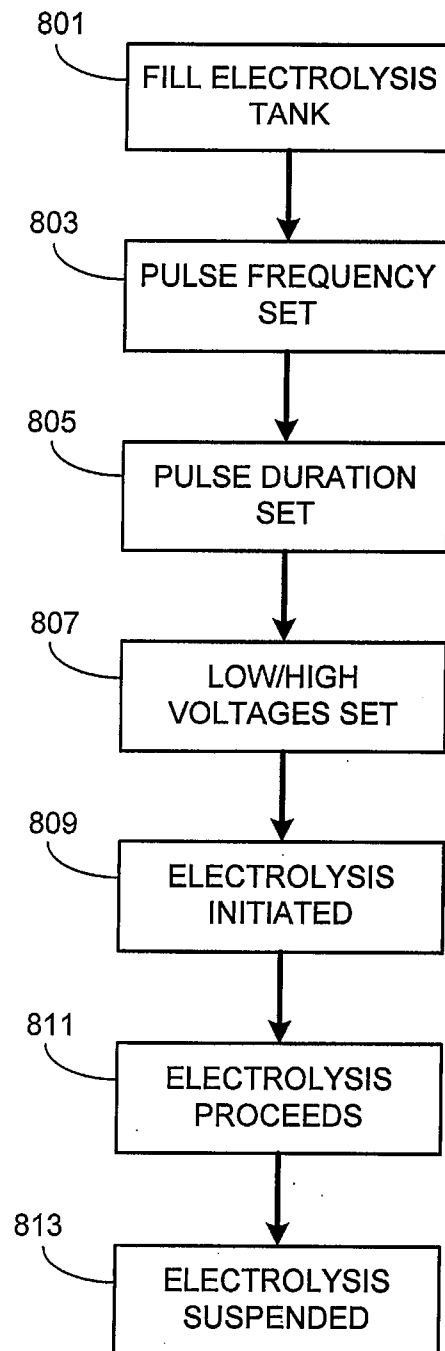


FIG. 8

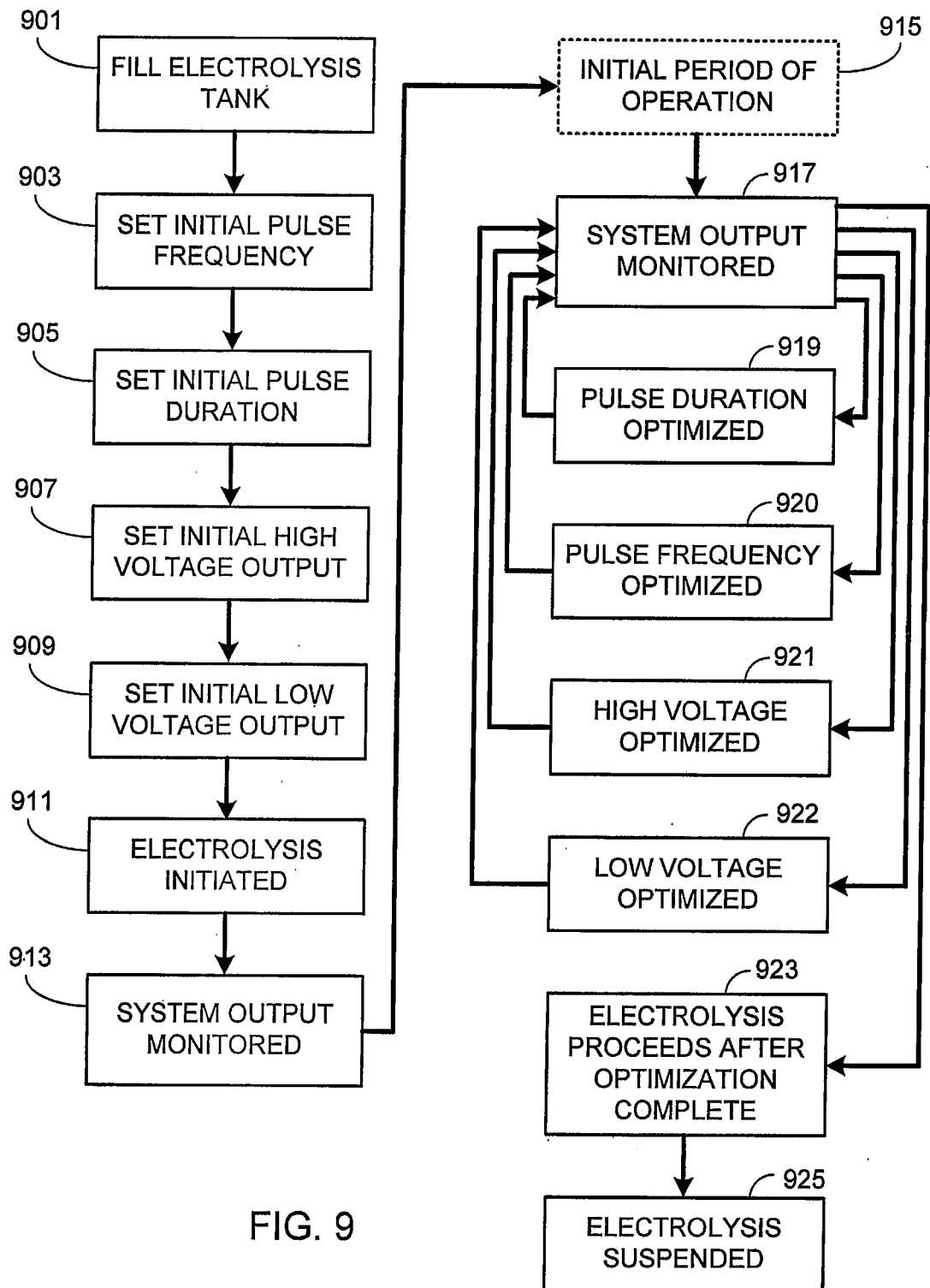


FIG. 9

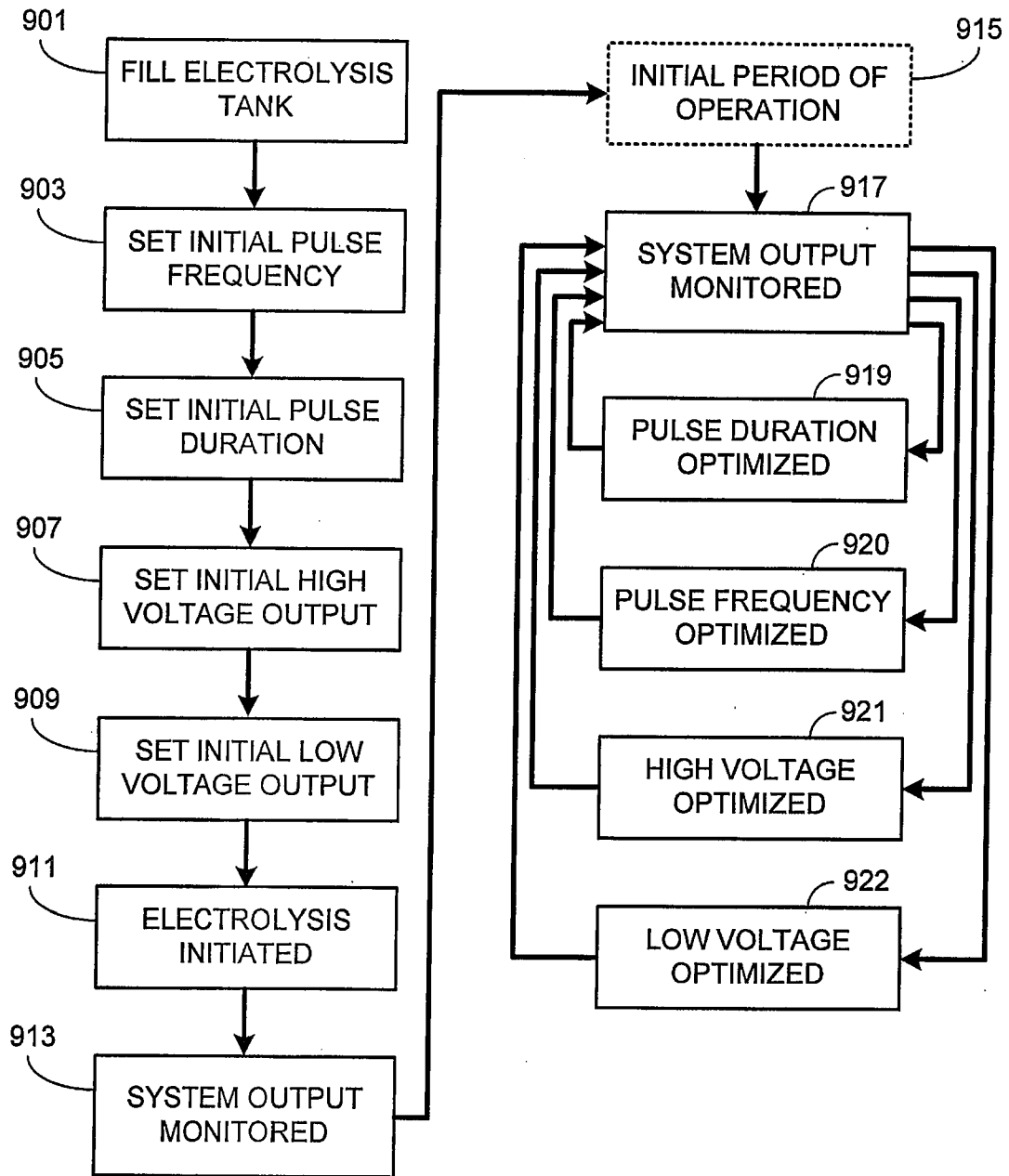


FIG. 10

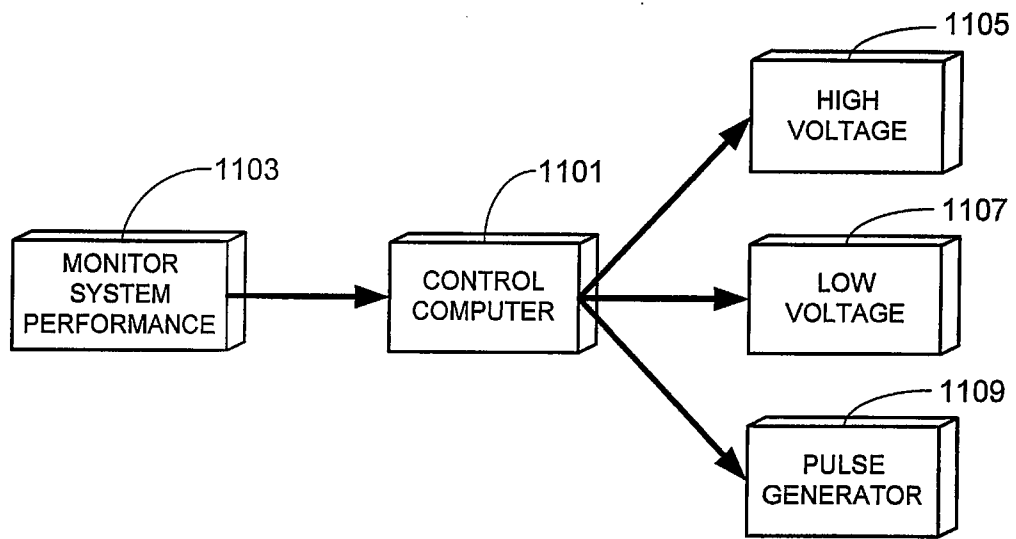


FIG. 11

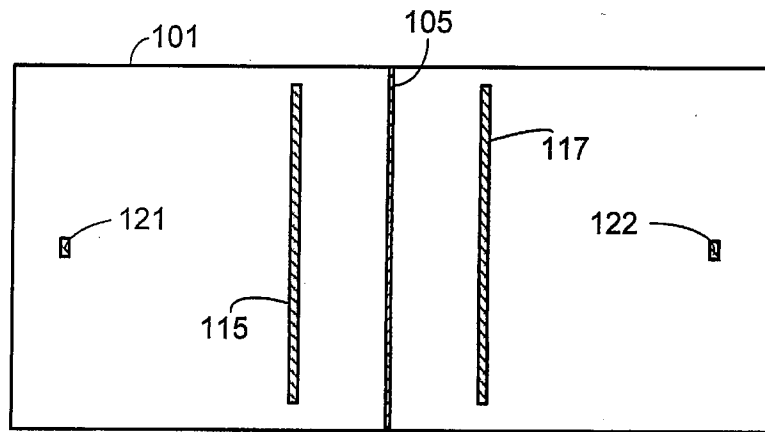


FIG. 12