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(71) Applicant: **AVGC TECHNOLOGY INNOVATION, LLC** [US/US]; 6206 Raintree Dr., Pearland, Texas 77584 (US).

(72) Inventors: **VIGEN, Eric**; 1228 Tate Cir., Sherman, Texas 75090-3466 (US). **COOPER, Mark**; 4149 Pirates Beach, Galveston, Texas 77554 (US). **GOODNIGHT, Gregg**; 6206 Raintree Dr., Pearland, Texas 77584 (US).

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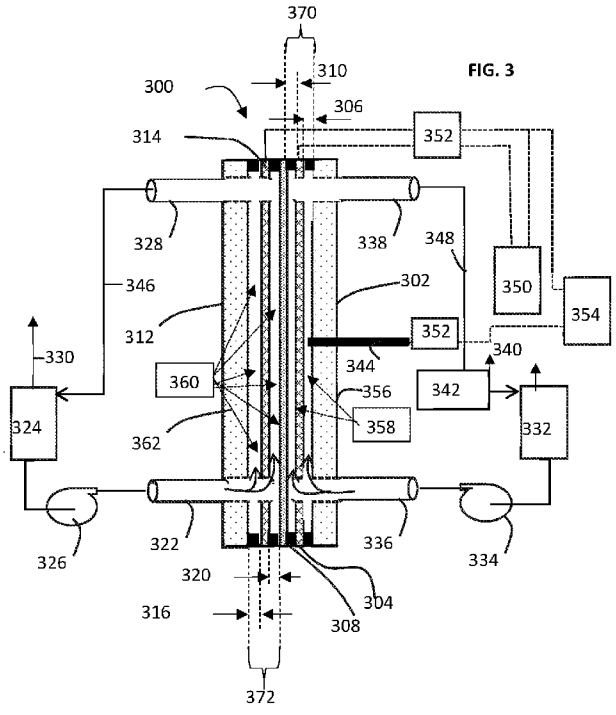

FIG. 3

(57) Abstract: An electrolysis cell and a method of using are disclosed herein. The electrolysis cell comprising a source of electromagnetic radiation configured to irradiate at least a portion of the cell at a first wavelength range suitable to increased production rates of hydrogen gas and improved energy efficiency during the electrolytic decomposition of water under the electrolytic hydrolysis conditions.

[Continued on next page]

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ELECTROLYSIS CELL AND METHOD TO PRODUCE HYDROGEN

FIELD

[0001] Embodiments of the present disclosure generally relate to an electrolysis cell and methods to produce hydrogen gas. More specifically to an electrolysis cell and methods to produce hydrogen gas via electrolysis, including aqueous electrolysis.

BACKGROUND

[0002] Hydrogen production has become an emerging replacement fuel. Hydrogen may be sourced from carbon-free power sources such as wind and solar (so-called "green hydrogen). It is non-fossil fuel, and the results of its use is a) beneficial thrust, and b) output that is H_2O water vapor instead of the disfavored carbon CO_2.

[0003] Current hydrogen production includes natural gas reformation, a fossil fuel-based process that involves the formation of carbon dioxide as a byproduct, and electrolysis, typically from splitting H_2O to produce H_2 and O_2 gas. Electrolysis has the potential to avoid the formation of carbon dioxide and other carbon emissions.

[0004] Current methods of electrolytic production of hydrogen utilize membranes which are permeable to protons, e.g., proton exchange membranes (PEM), which are typically employed under acidic conditions at a pH at or below 7, or a membrane which is permeable to hydroxyl anions e.g., a hydroxyl exchange membrane (OHEM), which is typically utilized under basic conditions e.g., at a pH at or above 7. However, these semi-permeable transport membranes form a rate-limiting step in the process, and are prone to contamination and/or poisoning, and present issues of scaleup of electrolytic cells due to the fragile nature of such materials. Instead of making the cells larger to increase the amount of hydrogen gas produced, a plurality of smaller electrolytic cells is combined to increase production, resulting in increased complexity. Furthermore, PEM electrolyzers employ catalysts based on precious metals such as platinum and iridium. Our methods are compatible with the technology designated as alkaline electrolysis and provides an improvement in this class of technology overcoming its inherent limitations. At the same

time, it provides a method to avoid the excessive material of construction and catalyst cost limitations of PEM (acidic) electrolysis technology.

[0005] The relatively thin semipermeable membranes utilized, however, provide a minimum gap between the cathode wherein the hydrogen gas is produced, and the anode wherein the oxygen gas is produced in an aqueous cell. Often allowing for essentially zero gap between the two electrodes, limited only by a thickness of the membrane. However, this too provides other obstacles directed to gas release upon formation.

[0006] Further, pure H_2O has a relatively low electrical conductivity such that the electrolyte which provides electrical connection between the anode and the cathode often includes an electrolyte to allow efficient conversion of electrical energy into hydrogen and oxygen.

[0007] There is a need in the art to improve the efficiency of electrolysis and the production of hydrogen gas.

SUMMARY

[0008] Methods and electrolysis cell for electrolytic hydrolysis are provided herein. In some embodiments, an electrolysis cell comprises a first chamber separated from, and in fluid communication with a second chamber through a first semi-permeable divider; a cathode disposed within the first chamber in wired electrical communication with an anode disposed within the second chamber through a first external electrical power source; the electrolysis cell configured to produce a first rate of hydrogen gas production efficiency within the first chamber when an aqueous electrolyte is present within the first and second chambers and an electrical potential is applied between the anode and the cathode under electrolytic hydrolysis conditions; a first source of electromagnetic radiation configured to irradiate at least a portion of the first chamber at a first wavelength range suitable to increase a production rate of hydrogen gas during electrolytic hydrolysis under the electrolytic hydrolysis conditions to a second rate of hydrogen gas production efficiency which is greater than the first rate of hydrogen gas production efficiency.

[0009] In embodiments, an electrolysis cell comprises a cathode chamber comprising a cathode disposed therein, separated from, and in fluid communication with an

intermediate chamber through a first membrane; an anode chamber comprising an anode disposed therein, separated from, and in fluid communication with the intermediate chamber through a second membrane; wherein the cathode is in wired electrical communication with the anode through a first DC power supply; wherein the first membrane is selectively permeable to protons and the second membrane is selectively permeable to hydroxyl ions; the electrolysis cell configured to produce a first rate of hydrogen gas production efficiency within the first chamber when an aqueous electrolyte is present within the cathode chamber, the intermediate chamber, and the anode chamber and an electrical potential is applied between the anode and the cathode under electrolytic hydrolysis conditions; and a first source of electromagnetic radiation configured to irradiate at least a portion of the cathode chamber at a first wavelength range suitable to increase production of hydrogen gas during electrolytic hydrolysis under the electrolytic hydrolysis conditions to a rate of hydrogen gas production efficiency which is greater than the first rate of hydrogen gas production efficiency.

[0010] In embodiments, a method of producing hydrogen comprises directing a first electrolyte stream into a first chamber of an electrolysis cell comprising a cathode disposed within the first chamber; directing a second electrolyte stream into a second chamber of the electrolysis cell comprising an anode disposed within the second chamber; wherein the first chamber is separated from, and in fluid communication with the second chamber through a first semi-permeable divider; applying a first DC electrical current to the cathode and the anode at a temperature and at a potential sufficient to produce hydrogen from the cathode; and irradiating at least a portion of the first chamber with electromagnetic radiation at a first wavelength range to produce hydrogen from the cathode.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Embodiments of the present disclosure, briefly summarized above and discussed in greater detail below, can be understood by reference to the illustrative embodiments of the disclosure depicted in the appended drawings. However, the appended drawings illustrate only typical embodiments of the disclosure and are therefore not to be

considered limiting of scope, for the disclosure may admit to other equally effective embodiments.

[0012] FIG. 1 depicts a Hemichem graphic representation of electrolysis of a water molecule at a corner or an edge of an electrode.

[0013] FIG. 2 depicts a Hemichem graphic representation of a lack of electrolysis of a water molecule along a flat surface of an electrode.

[0014] FIG. 3 is a block diagram depicting an electrolysis cell and system according to embodiments disclosed herein.

[0015] FIG. 4 is an overhead view of a block diagram depicting an electrolysis cell according to embodiments disclosed herein.

[0016] FIG. 5 is a perspective drawing of a fiberoptic element of an electrolysis cell according to embodiments disclosed herein.

[0017] FIG. 6 depicts a Hemichem graphic representation of electrolysis of a water molecule to produce hydrogen, facilitated with electromagnetic radiation according to embodiments disclosed herein.

[0018] FIG. 7 depicts a Hemichem graphic representation of electrolysis of a water molecule to produce oxygen, facilitated with electromagnetic radiation according to embodiments disclosed herein.

[0019] FIG. 8 depicts an electrolysis cell having multiple membranes according to embodiments disclosed herein.

[0020] FIG. 9 depicts an electrolysis cell having multiple membranes according to other embodiments disclosed herein.

[0021] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. The figures are not drawn to scale and may be simplified for clarity. Elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

DETAILED DESCRIPTION

[0022] Embodiments disclosed herein include reference to a hemispherical model, referred to herein as a Hemichem model, which provides physical modelling of the underlying chemistry and subatomic physics using hemispherical coordinates (r_z,θ_z,a_z,z_z=X0=±½), replacing quantum numbers (n,l,m_l,m_s). The hemispherical model further utilizes acceleration allocation (aa) always at the system center-of-mass, thereby replacing Newton's 2nd Law of Motion wherein three core interactions are utilized to generate the fundamental forces, including full integration of gravity.

[0023] For purposes herein, elementary particles are considered to be elementary-event sets of multiple core particles, arranged in three dimensional (3D) engineering stable structures. The Hemichem model provides 3D engineering physical arrangement, along with causation of quantum equations in terms of classical physical understanding and calculations. Current quantum mechanical analysis is based on statistical techniques which remain valid for multiple particles and multiple events. However, current quantum mechanical analysis cannot describe a single event or particle. In contrast, the Hemichem model utilized herein provides a means of obtaining information in terms of 3D engineering of quantum equations known in the art by incorporating an additional frame-of-reference. Various known dilemmas, such as improper infinities and the like are resolved by the Hemichem model, rendering statistical quantum techniques redundant.

[0024] However, the Hemichem method referred to herein does not detract from, and is in overall agreement with the multitude of information readily known to one of skill in the art of quantum mechanics (QM), quantum field theory (QFT), and the like. The Hemichem method utilized herein presents revisions to known relationships which bridge classical single particle-particle events-sets with the multiple-event quantum prediction techniques and experimental evidence.

[0025] A detailed description of the methods and models utilized herein, including the HemiChem model and the application thereof, may be found in the HemiChem IDS series including Vigen, A. (4-17-2024). Hemispherical Atomic Model ISBN 9798870681290, Vigen, A. (12-23-2023). The Nature and Causation of Light, Photons, and EM Waves Amazon-ASIN B0CQWN1NT4; Vigen, A. (3-1-2024). First Principles for Subatomic

Physics Amazon-ASIN: B0CWTYVX7Q; and the like. Additional references include Vigen, A. (1-28-2023). HemiQuantum Physics: Resolving Each Quantum Dilemma: Improving Each Quantum Technique from Planck's Equation to Elementary Particles, Amazon-ASIN B0BTC7PGND; Vigen, A. (1-19-2019). Understanding Pauli's ½ as 3D Hemispheres Fully Links Quantum Theory to Classical Physics, Amazon-ASIN B07MYNTPJ7; Vigen, A. (1-18-2019). Simple Words to Fully Reconcile Classical Mechanics with Quantum Theory, Amazon-ASIN B07MY9CH4F; Vigen, A. (4-25-2022).Refining the Schrödinger Wave Function Equation in Hemispherical (r,θ,φ,z=X0=±½) Coordinates Amazon-ASIN B09YWSL1FR; Vigen, A (10-12-2016).Gravity is Just That Electrons are a Little Closer; Amazon-ASIN B01M9B4V4E; Vigen. A (10-13-2016). Electron Shell Chemistry is Just Scrunched Cube Geometry; Amazon-ASIN B01M7PRGWZ; Vigen. A (1-19-2019).Revising Planck-Einstein Energy Equation to Add Pauli's ½ Fully Links Quantum Theory to Classical Physics; Amazon-ASIN(B07MYLTJ67); Vigen. A (1-18-2018). Postulated Nucleostaticmagnetics Force for Subatomic Particles Resolves Dirac's 1931 Monopoles as Fully Deterministic Duopoles; Amazon-ASIN B07MY7F289; Vigen. A (3-25-2023).The Mass Equation: My Breakthrough Position-in-Field Approach from Hemispherical (r,θ,φ,z=X0=±½); Amazon-ASIN B0BZN3MGNC; Vigen A. (10-2-2020). Replacement of Bohr's Angular Momentum with Strong Nuclear Force for Electrons; Amazon-ASIN B08KNMVPB1; Vigen, A (6-20-2020). Nucleostaticmagnetics Vector Equations; Amazon-ASIN B08BKW46GG; Vigen, A. (3-2-2020). Math Integrity Understanding Strong and Weak Force Through the Forces / Fields of Electrostatic, Direct and Axial Nucleostaticmagnetics: 4-Vector in 3D Model Generating Four Quantum Equations (Dirac); Amazon-ASIN B085R99M44; Vigen, A. (1-18-2020). Renaissance Physics: Understanding Post-Quantum Novo-Classical Subatomic Particle Engineering Textbook Chapter 1-4 Amazon ISBN 1659185777; Vigen, A. (3-31-2019). 3D Visual Chemistry Textbook; Amazon-ASIN B07Q3PY8GV; Vigen, A. (1-18-2018). Quantum Entanglement, Wave Functions, and Spectrum Given the 3D Arno Vigen Scrunched Cube (AVSC) Atomic Model; Amazon-ASIN B07MY7Y5ZW; Vigen, A. (10-8-2017). Fixing Einstein's E=mc-squared: Replacing Observed Mass ('m') with the 'M' Nucleus Magnetic Force Divided by the Volume of the Electron Shell Radius Separation; Amazon-ASIN B0769ZJK9K; Vigen, A. (10-29-2016).

Why Does a Nucleus Stay Together When Protons (+) Repel Each Other?: A Nucleus is Just . . . a Magnetic Chain-Ring; Amazon-ASIN B01M73KXNQ; The full disclosures of each are fully incorporated by reference herein.

[0026] As used herein, radial electrostatic (rES) interaction / force refers to an electrostatic (ES) attribute often referred to as charge in the prior art, having an appropriate sign of positive (+) or negative (-) or zero for neutrons. The operating rules associated with radial electrostatic (rES) interaction is that opposites attract and like-kind repel.

[0027] Xtrastatic (XS) axis refers to the magnetic axis inherent in every subatomic particle (fermions) according to the Hemichem model. Axial xtrastatic interaction and/or force refers to the attractive force from a particle (P1), or more specifically from its two hemispheres / poles, towards the axis of a second particle (P2). The sign of the interaction being based upon the XS-attribute known as mass in prior art. The operating rules associated with xtrastatic (XS) interaction as like kind zero and difference generating two force vectors rXS isotropic repulsive with aXS as anisotropic attribute to the axis of the other particle-set. These also split between portions as linear towards-the-axis and portions as rotational of the axis itself.

[0028] Radial extrastatic interaction and/or force refers to the repulsive force from a particle (P1) from its two differentiated axis / hemispheres away from a second particle (P2). This sign of this interaction is based upon the XS-attribute also referred to as mass according to common understanding in the art.

[0029] In addition, it is understood that like-kind particles do not have xtrastatic interactions. Only the electron-proton, and the electron-nucleon have xtrastatic interactions.

[0030] For purposes herein, consistent with the Hemichem model, particle-edge and maximum field strength occurs at a particle's physical dimension radius, (r_e). Accordingly, for purposes herein, a proton is assumed to have a radius and position-in-field maximum at (r_e).

[0031] For purposes herein, calculation of the behavior of each hemisphere is defined from a pole to an equator of the hemisphere by the inherent XS axis over the body of the

particle. The body of the particle having a center-of-substance defined in hemispherical coordinates (r_z,θ_z,φ_z,z_z=X0=±½) as ((3/8)r_z,0,0,+½) for a first hemisphere, and ((3/8)r_z,0,0,-½) for the other second hemisphere, which is locked-at-180° relative to the first hemisphere.

[0032] As used herein, radial electrostatic force – (rES) – refers to the interaction between protons and electron based upon the charge attribute with the product as the interactions. Accordingly, "opposites attract" and "like-kind repel" based upon the following table wherein neutrons do not experience interactions with either a proton or an electron.

[0033] Table 1 depicts the interactions for subatomic particles for radial electrostatic (rES) interactions.

[0034] For the radial electrostatic (rES) interactions, the logic table for types is based upon the product of the signs. The rES 'charge' attributes are as follows:

Proton = (+1); Neutrons = 0; and Electrons = (-1); which are shown in the Table 1:

TABLE 1 OF ELECTROSTATIC CHARGE INTERACTIONS

	Proton (+)	Neutron (0)	Electrons (-)
PROTON	(+)(+) = (+)	(0)(+) = (0)	(+)(-) = (-)
NEUTRON	(+)(0) = (0)	(0)(0) = (0)	(-)(0) = (0)
ELECTRONS	(+)(-) = (-)	(0)(-) = (0)	(-)(-) = (+)

wherein the xtrastastic, pre-magnetism subatomic force, the interaction logic table is based upon two force vectors:

i) Radial xtrastatic, the outward 'at the equator; and

ii) Axial xtrastatic, the inward towards-the-axis.

[0035] These operate by 'like-kind zero' and both operating in different directions with an overall sign opposite to rES. That is the formula is (SIGN)(product) wherein both protons and neutrons have this 'mass' attribute as (+1).

[0036] For the XS 'mass' attribute the assigned attributes are:

Proton = (+1), Neutrons = (+1) and Electrons = (-1), wherein the radial xtrastatic (rXS), using sign = (-1), is shown in Table 2:

TABLE 2 OF XTRASTATIC CHARGE INTERACTIONS

	Proton (+)	Neutron (0)	Electrons (-)
PROTON	same = (0)	same = (0)	(-)((+)(-)) = (+)

NEUTRON	same = (0)	same = (0)	(-)((+)(-)) = (+)
ELECTRONS	(-)((+)(-)) = (+)	(-)((+)(-)) = (+)	same = (0)

Axial xtrastatic (aXR) (using sign = (+1)) as shown in Table 3:

TABLE 3 OF NUCLEOSTATIC CHARGE INTERACTIONS

	Proton (+)	**Neutron (0)**	**Electrons (-)**
PROTON	same = (0)	same = (0)	(+)((+)(-)) = (-)
NEUTRON	same = (0)	same = (0)	(+)((+)(-)) = (-)
ELECTRONS	(+)((+)(-)) = (-)	(+)((+)(-)) = (-)	same = (0)

[0037] The combination two static force vectors of the axial xtrastatic force is out-at-equator, inward-towards-axis of pre-magnetism, and the electron subshells, which relates to the inclination ring-spring physics underlying Bose proof of quantum mechanics (QM).

[0038] Elemental Ionization Energy – (Ei,N) refers to the energy to remove an electron of a chosen element and molecular state. For example, the energy required to remove an electron from a hydrogen atom to isolate a proton, wherein N = 1 for hydrogen.

[0039] Molecular Ionization Energy – (Ei,AB-) refers to the energy to remove an electron of a chosen elements and molecular state. For example, the energy required to ionize water to produce a hydronium or hydrogen ion $(H_2O)+$. In this example, the AB notation above is H_2O.

[0040] As used herein, a physics spin isolated electromagnetic energy beam refers to a monochromatic electromagnetic beam consisting essentially of a plurality of spin-isolated photons, wherein the spin-isolated photons are only observable within a plurality of first discrete ranges along a path of the monochromatic electromagnetic beam, each of the first discrete ranges centered at a corresponding distance from a source of the monochromatic electromagnetic beam, wherein essentially no photons are observable within a plurality of second discrete ranges located in-between each of the first discrete ranges, as described in the Applicant's corresponding US Patent Application No. 18/674,995, filed May 27, 2024, the disclosure of which is incorporated by reference herein.

[0041] For purposes herein, an increase in a rate of hydrogen gas production efficiency during electrolytic hydrolysis under the electrolytic hydrolysis conditions to a rate of hydrogen gas production efficiency which is greater than the first rate of hydrogen gas

production efficiency refers to the efficiency of production, and includes both an increase in hydrogen gas production to the second rate using the same amount of electrical current used to achieve the first hydrogen gas production rate, i.e., improved efficiency based on the amount of hydrogen produced per unit of electrical current used, and/or the second rate of hydrogen gas production produces the same amount of hydrogen gas as produced in the first rate of hydrogen gas production, using less electric current than was used in the first rate of hydrogen gas production.

[0042] For purposes herein hydrolysis conditions include the particular electrolyte, voltage, power, temperature, flow rates, pressures, concentrations, and the like required to produce hydrogen gas via electrolysis of water in the subject apparatus.

[0043] The anode of the electrolytic cell is where reduction takes place, which for water electrolysis has a negative charge, and the cathode is the electrode wherein oxidation takes place, which for water hydrolysis has a positive charge.

[0044] In embodiments, an electrolysis cell comprises a first chamber separated from, and in fluid communication with a second chamber through a first semi-permeable divider; a cathode disposed within the first chamber in wired electrical communication with an anode disposed within the second chamber through a first DC power supply; the electrolysis cell configured to produce a first rate of hydrogen gas production efficiency within the first chamber when an aqueous electrolyte is present within the first and second chambers and an electrical potential is applied between the anode and the cathode under electrolytic hydrolysis conditions; a first source of electromagnetic radiation configured to irradiate at least a portion of the first chamber at a first wavelength range suitable to increase production of hydrogen gas during electrolytic hydrolysis under the electrolytic hydrolysis conditions to a rate of hydrogen gas production efficiency which is greater than the first rate of hydrogen gas production efficiency.

[0045] In embodiments, the first wavelength range for hydrogen gas (H_2) production is plus or minus about 50 nm of an emission line produced from a hydrogen emission spectrum. In embodiments, the first wavelength range is from about 606 nm to about 706 nm. In embodiments, the electrolysis cell further comprises a second source of electromagnetic radiation configured to irradiate at least a portion of the second chamber

at a second wavelength range suitable to increase production of hydrogen gas during electrolytic hydrolysis under the electrolytic hydrolysis conditions to a rate of hydrogen gas production efficiency which is greater than the first rate of hydrogen gas production efficiency. In embodiments, the second wavelength range is about plus or minus 50 nm of an emission line produced from an oxygen emission spectrum. In embodiments, the second wavelength range is from about 347 nm to about 447 nm for oxygen (O_2) gas production.

[0046] In embodiments, the first semi-permeable divider is selectively permeability to protons. In embodiments, the first semi-permeable divider is selectively permeability to hydroxyls ions. In embodiments, the semi-permeable divider is a porous membrane having a porosity of less than or equal to about 100 microns, or less than or equal to about 50 microns, or less than or equal to about 10 microns. In embodiments, the semi-permeable divider is a hydrophobic porous membrane. In embodiments, the semi-permeable divider is a hydrophilic porous membrane.

[0047] In embodiments, the electrolysis cell further comprises an external magnetic field source configured to provide a magnetic field between two magnetic poles through at least a portion of the first chamber, the second chamber, or both, wherein the two magnetic poles are arranged such that a line extending between a center of each of the two magnetic poles is oriented at an angle from about 2° to about 90° relative to a line extending between a center of the cathode, through the first semi-permeable divider to a center of the anode i.e., opposing faces of the cathode and the anode.

[0048] In embodiments, an outer face of the cathode is spaced away from a first chamber wall by a first distance, and an inner face of the cathode is spaced away from the first semi-permeable divider by a second distance, an outer face of the anode is spaced away from a second chamber wall by a third first distance, and an inner face of the anode is spaced away from the first semi-permeable divider by a fourth distance; wherein a first electrolyte is pumped through a cathode inlet into contact with the cathode through the first distance and the second distance and out of the electrolysis cell through a cathode outlet; wherein a second electrolyte is pumped through an anode inlet into contact with the anode through the third distance and the fourth distance and out of the electrolysis

cell through an anode outlet; wherein the first distance, the second distance, the third distance, and the fourth distance are independently greater than or equal to about 0.5 mm, or greater than or equal to about 1 mm, or greater than or equal to about 1.5 mm, or greater than or equal to about 2 mm. In embodiments, a distance between the inner face of the cathode and an inner face of the anode (through the first semi-permeable divider) is less than or equal to about 10 mm, or less than or equal to about 5 mm, or less than or equal to about 1 mm.

[0049] In embodiments, the electrolysis cell further comprises a plasma-producing cathode electrode in electrical communication with a second DC power supply in wired electrical communication between the anode and the plasma cathode, the second DC power supply configured to provide a voltage potential between the anode and the plasma cathode sufficient to produce a plasma under the hydrolysis conditions.

[0050] In embodiments, the electrolysis cell is configured to provide a repeating pulsed voltage cycle comprising providing a low voltage pulse potential from the first DC power supply between the cathode and the anode for a first period of time; followed by a first rest period of time wherein no potential is applied between the cathode and the anode, or between plasma cathode and the anode; followed by a plasma voltage pulse potential from the second DC power supply between the plasma cathode and the anode for a second period of time; followed by a second rest period of time wherein no potential is applied between the anode and the cathode or the plasma cathode; wherein the cycle repeats. In embodiments, the first period of time is greater than each of the second period of time, the first rest period of time, and the second rest period of time. In embodiments, the first rest period of time is essentially equal to the second rest period of time.

[0051] In embodiments, during the first rest period of time and the second rest period of time, the anode and the cathode are electrically isolated from the first DC power supply and the anode and the plasma cathode are electrically isolated from the second DC power supply and/or, in embodiments, during the first period of time, the anode and the plasma cathode are electrically isolated from the second DC power supply and/or in embodiments, during the second period of time, the anode and the cathode are electrically isolated from the first DC power supply.

[0052] In embodiments, an electrolysis cell comprises a cathode chamber comprising a cathode disposed therein, separated from, and in fluid communication with an intermediate chamber through a first membrane; an anode chamber comprising an anode disposed therein, separated from, and in fluid communication with the intermediate chamber through a second membrane; wherein the cathode is in wired electrical communication with the anode through a first DC power supply; wherein the first membrane is selectively permeable to protons and the second membrane is selectively permeable to hydroxyl ions; the electrolysis cell configured to produce a first rate of hydrogen gas production efficiency within the first chamber when an aqueous electrolyte is present within the cathode chamber, the intermediate chamber, and the anode chamber and an electrical potential is applied between the anode and the cathode under electrolytic hydrolysis conditions; and a first source of electromagnetic radiation configured to irradiate at least a portion of the cathode chamber at a first wavelength range suitable to increase production of hydrogen gas during electrolytic hydrolysis under the electrolytic hydrolysis conditions to a rate of hydrogen gas production efficiency which is greater than the first rate of hydrogen gas production efficiency.

[0053] In embodiments, the electrolysis cell further comprises a second source of electromagnetic radiation configured to irradiate at least a portion of the anode chamber at a second wavelength range suitable to increase production of hydrogen gas during electrolytic hydrolysis under the electrolytic hydrolysis conditions to a rate of hydrogen gas production efficiency which is greater than the first rate of hydrogen gas production efficiency.

[0054] In embodiments, the electrolysis cell further comprises a third source of electromagnetic radiation configured to irradiate at least a portion of the intermediate chamber at a third wavelength range suitable to increase production of hydrogen gas during electrolytic hydrolysis under the electrolytic hydrolysis conditions to a rate of hydrogen gas production efficiency which is greater than the first rate of hydrogen gas production efficiency.

[0055] In embodiments, a method to produce hydrogen gas comprises directing a first electrolyte stream into a first chamber of an electrolysis cell comprising a cathode

disposed within the first chamber; directing a second electrolyte stream into a second chamber of the electrolysis cell comprising an anode disposed within the second chamber; wherein the first chamber is separated from, and in fluid communication with the second chamber through a first semi-permeable divider; applying a first DC electrical current to the cathode and the anode at a temperature and at a potential sufficient to produce hydrogen from the cathode; and irradiating at least a portion of the first chamber with electromagnetic radiation at a first wavelength range to produce hydrogen from the cathode.

[0056] In embodiments, the method further comprises applying an external magnetic field between two magnetic poles through at least a portion of the first chamber, the second chamber, or both, wherein the two magnetic poles are arranged such that a line extending between a center of each of the two magnetic poles is oriented at an angle from about 2° to about 90° relative to a line extending between a center of the cathode, through the first semi-permeable divider to a center of the anode.

[0057] In embodiments, the method further comprises applying a second DC electrical current between a plasma cathode and the anode at a potential sufficient to produce a plasma within the first electrolytic cell's electrolyte, wherein the first DC electrical current and the second DC electrical current are provided in a repeating pulsed voltage cycle comprising: providing the first DC electrical current as a pulse between the cathode and the anode for a first period of time; followed by a first rest period of time wherein no potential is applied between the cathode and the anode, or between the plasma cathode and the anode; followed by providing the second DC electrical current as a pulse between the plasma cathode and the anode for a second period of time; followed by a second rest period of time wherein no potential is applied between the cathode and the anode, or between the plasma cathode and the anode; wherein the cycle repeats.

[0058] The instant disclosure is generally directed to electrolytic hydrolysis. Suitable electrolytic hydrolysis may include, but is not limited to the electrolytic hydrolysis of water to produce hydrogen and oxygen. For purposes of brevity, the disclosure references electrolytic hydrolysis of water to produce hydrogen and oxygen. However, it is to be understood that embodiments disclosed herein may also be applicable to other forms of

hydrolysis, and are not limited to only aqueous hydrolysis to produce hydrogen and oxygen. Furthermore, it is to be understood that a plurality of electrolytic cells according to embodiments disclosed herein may be combined in a stacked arrangement such that an outer plate or cell wall of one electrolysis cell may also form an outer plate or cell wall of another electrolysis cell.

[0059] Aqueous hydrolysis under acidic conditions includes reduction at the cathode

$$2H^+(aq) + 2e^- \rightarrow H_2(g);$$

and oxidation at the anode

$$H_2O(l) \rightarrow 1/2\ O_2(g) + 2\ H^+(aq) + 2e^-.$$

Aqueous hydrolysis under basic conditions includes reduction at the cathode:

$$2\ H_2O(l) + 2e^- \quad \rightarrow \quad H_2(g) + 2\ OH^-(aq);\ \text{and}$$

oxidation at the anode:

$$2\ OH^-(aq) \quad \rightarrow \quad O^{-1}(g) + O(g) + H + H.$$

then as hydrogen passes to next chamber, the EM wave (2 photons) get the free oxygens into the open-valence state to form O2:

$$O^{-1}(g) + O(g)^{-1} + 2\gamma \rightarrow \quad O(g) + O(g) + 2\ e^-$$

$$O(g) + O(g) \quad \rightarrow \quad O_2(g).$$

[0060] Combining either half reaction pair yields the same overall decomposition of water into oxygen and hydrogen:

$$2\ H_2O(l) \rightarrow 2\ H_2(g) + O_2(g).$$

[0061] Accordingly, aqueous hydrolysis results from splitting two hydrogen atoms from a water molecule which recombine with to become hydrogen gas with a corresponding consumption of two electrons. A 100%-efficient aqueous electrolysis would consume 39.4 kilowatt-hours per kilogram of hydrogen produced. However, this value is dependent on the temperature, pressure, and other factors. The minimum electric potential required for aqueous hydrolysis is −1.229 V at 25 °C (which is generally considered to be independent of pH within reasonable error).

[0062] The Applicant has observed that by providing a direct path to the positive charged oxygen nucleus, hydrolysis is facilitated. By applying 3D engineering according to the HemiChem methodology, excess electrons are allowed between two free hydrogen protons (H+) creating an intermediate represented via the HemiChem model as (H-e-H)+. Both ends of the intermediate species are positive, and the center shared electron is negative, forming an electrostatic positive cation in all directions. The (OH) have the hydrogen oriented in one direction and an oxygen in the other, creating an rES dipole in which one side is rES positive and the other is rES negative. By configuring the electrolysis cell according to embodiments disclosed herein, the H-e-H intermediate species is allowed to react with an electron via rES attraction to produce a stable environment with rES neutral HO and the H_2 , which by virtue of being a gas leaves the system.

[0063] The inventors have observed that the transition of water into hydrogen and oxygen occurs at positions on the electrodes with angled surfaces, wherein the sharper the angle, the more gas which is produced. That is the hydrogen production is greatest at corners suggests that hydrogen covalent bonding electrons require a penetration by the corner.

[0064] FIG. 1 depicts electron removal in an aqueous electrolysis system 100 at an edge or corner (edge/corner 104) of an electrode 102. A H_2O molecule 106 includes an oxygen atom 108 having six valence electrons at the corners of a cube. The target hydrogen proton 110 has an electron 112 shared (dotted line) with the oxygen 108, which is pointed inward relative to the oxygen open valence positions at the corners of the cube. The hydrogen proton 110 is exterior to the oxygen 108 shell structure thus providing it with one bonding position toward the bonding electron 112. However, the hydrogen proton 110 further includes a 2nd bonding position 116 (open circle) allowing for the formation of hydrogen bonds between water molecules. In the geometry shown, the target electron 112 for removal is at an inside angle relative to the oxygen 108 and the hydrogen proton 110.

[0065] Because the rES charge for the electrode 102 is strongest at the outermost positions, e.g., the edge/corner 104, and that edge/corner 104 is dimensioned to fit within the angles formed between the hydrogen and oxygen atoms, there are positions as

illustrated where the electrode 102 edge/corner 104 is closer to the target electron 112 than either the remaining portion of the electrode 102 or the hydrogen proton 110 are to the target electron 112. As a result, the target electron 112 moves toward the electrode 102 as indicated by the arrow 114. The result is separation of the hydrogen proton 110 as a H+ from the oxygen atom 108. This results in the oxygen having a rES value of neutral, but a valence of positive 1 (+1) thus seeking to replace a negative charge into the opening created by removal of the electron 112 and formation of the hydrogen proton 110.

[0066] FIG. 2 depicts an interfering configuration 200 wherein a flat surface of the electrode 102 is proximate to the water molecule such that the hydrogen proton 110 is disposed in-between the electrode 102 and the target electron 112 preventing removal of the target electron 112 and the formation of the H+ proton. Accordingly, little to no reaction takes place on flat featureless sections of the electrode 102. The hydrogen proton 110 thus interferes 202 with the formation of the hydrogen gas.

[0067] The same processes result in both the spitting of OH to produce oxygen gas, and the formation of hydrogen gas which requires an electron. However, there are several available paths for the reactions where just the H+ is split resulting in an oxygen left as at a valance of 0, but having an rES charge of -2. This pathway results in the lack of an available electrons required to produce hydrogen gas.

[0068] In addition, the higher 2nd ionization of oxygen further decreases the available hydrogen protons leaving an excess of oxygen in the solution, thereby resulting in a decrease in the production of hydrogen. The end result is a dynamic equilibrium based upon the lower production rate of O_2 via the anode.

[0069] In addition, oxygen is present as two double bonded oxygen atoms, thus a further transition is required. The reaction is not as simple as the oxygen atoms naturally aligning to become oxygen gas since the oxygens atoms present in the electrolyte are not free, but are instead present in various forms between water and hydroxyl ions. To overcome these various barriers, higher rates of hydrolysis may be achieved at higher temperatures. However, this results in lower overall efficiency.

[0070] Accordingly, several issues exist with limit the efficiency of electrolysis. These include the H^+ separation by radial electrostatic (rES) force from the cathode to limit the production of hydrogen and oxygen. The reduction to 'zero-gap' or minimal gap according to embodiments disclosed herein allows that interaction strength between molecules (at $1/(\text{distance})^2$ to be maximized. The H_2O present in the electrolytic cell which is not at an energy suitable for H^+ separation blocks and slows the volume of transport between the two sides of the cell, thus limiting the production of gas from the electrolytic cell.

[0071] In embodiments, EM waves are utilized to facilitate the transfer between the two or more chambers in the electrolytic cell below rES limits.

[0072] In embodiments, EM waves are utilized to facilitate the highest energy chemical reactions in the formation of hydrogen gas and oxygen gas from water, which includes the formation of the oxygen to oxygen double bonds. While electrolysis adds an electron, direct hydrolysis fails to facilitate the formation of the oxygen double bond.

[0073] Embodiments further include applying an electron displacement wherein the EM wave in one of the chambers facilitates the formation of hydrogen gas, and the EM wave in another of the chambers facilitates the formation of oxygen gas, creating a different chemical path to increase the gas production rate from the electrolytic cells.

[0074] In embodiments, electromagnetic energy is introduced into regions of the electrolytic cell to improve the generation of gas production at both the surfaces of the electrodes and in open space throughout the various chambers, wherein a wavelength of the electromagnetic energy is selected for each chamber or region of a chamber.

[0075] As depicted in FIG. 3, in an embodiment, the electrolytic cell 300 comprises a first outer plate 302 (e.g., a first chamber wall) separated from a cathode 304 (a negative electrode) by a first distance 306. The cathode 304 is separated from a first semi-permeable divider 308 by a second distance 310. The volume bound between the first outer plate 302 and the first semi-permeable divider 308 forming a first chamber 370.

[0076] The electrolytic cell 300 further comprising a second outer plate 312 (e.g., a second chamber wall) separated from an anode 314 (a positive electrode) by a third distance 316. The anode 314 is separated from the first semi-permeable divider 308 by

a fourth distance 320. The volume bound between the second outer plate 312 and the first semi-permeable divider 308 forming a second chamber 372.

[0077] The electrolytic cell 300 further includes an anode side electrolyte inlet 322 which provides fluid communication from an external anode reservoir 324, e.g., through an anode side pump 326. As shown in FIG. 3, in embodiments, an electrolyte is pumped between the second outer plate 312 and the anode 314 through the channel created by the third distance 316, and between the anode 314 and the first semi-permeable divider 308 through the channel created by the fourth distance 320. The electrolyte flows out of the electrolytic cell 300 through an anode side electrolyte outlet 328, which is in fluid communication with the external anode reservoir 324. Oxygen gas formed within the electrolytic cell 300 is separated from the anode side outward electrolyte 346 flowing out of the electrolytic cell 300 through the anode side electrolyte outlet 328. In embodiments, separation of oxygen gas from the electrolyte occurs in the external anode reservoir 324 as indicated by arrow 330. However, in embodiments, one or more liquid gas separators may be employed between the anode side electrolyte outlet 328 and the external anode reservoir 324.

[0078] In embodiments, the electrolyte is pumped by the cathode side pump 334 into the electrolytic cell 300 through the cathode side electrolyte inlet 336 an flows between the first outer plate 302 and the cathode 304 through the channel created by the first distance 306 and between the cathode 304 and the first semi-permeable divider 308 through the channel created by the second distance 310. The electrolyte flows out of the electrolytic cell 300 through a cathode side electrolyte outlet 338, which is in fluid communication with the external cathode reservoir 332. Hydrogen gas formed within the electrolytic cell 300 is separated from the cathode side outflowing electrolyte 348 flowing out of the electrolytic cell 300 through the cathode side electrolyte outlet 338, which in an embodiment occurs in the external cathode reservoir 332 as indicated by arrow 340, and/or within a liquid gas separator 342 arranged between the cathode side electrolyte outlet 338 and the external cathode reservoir 332.

[0079] In embodiments, the linear velocity of the electrolyte through the various channels formed by the first, second, third and fourth distances is sufficient to facilitate removal of the gas formed on the electrodes.

[0080] In embodiments, the anode 314 and the cathode 304 are in electrical communication with a first power supply 350 through a controller 352 configured to pulse a first lower DC voltage between the anode 314 and the cathode 304. In embodiments, this first voltage is greater than or equal to the minimum potential difference for water electrolysis under the conditions, e.g., temperature, pH, and the like, present in the electrolytic cell 300, which in embodiments is greater than or equal to about 1.23 V DC. In embodiments, the first voltage is from about 1.3 V DC to less than or equal to about 24 V DC.

[0081] In embodiments, the electrolytic cell 300 further includes a plasma cathode 344, in electrical communication with a second power supply 354, which is also in electrical communication with the anode 314 and the plasma cathode 344 through the controller 352 configured to provide a pulsed electrical potential to the plasma cathode 344. In embodiments, the plasma cathode 344 is pulsed at a voltage sufficient to produce an intermittent plasma e.g., a spark, within the electrolyte flowing through the electrolytic cell 300. In embodiments, the second power supply provides a DC voltage (a potential) sufficient to produce a plasma or a spark under conditions present within the electrolytic cell 300, which in embodiments is greater than or equal to about 90 V, or greater than or equal to about 110 V, or greater than or equal to about 150 V, or greater than or equal to about 200 V, and less than or equal to about 2000 V, or less than or equal to about 1000 V, or less than or equal to about 500 V. However, since the voltage required to produce the plasma depends on the conductivity of the electrolyte, e.g., a concentration of ionic species in the electrolyte, the voltage of the second power supply may be much higher, e.g., for water essentially devoid of an electrolyte such as an acid or a base a potential exceeding 2 kV may be required.

[0082] In embodiments, the controller is configured to establish an electrical connection between the first power supply 350, the anode 314 and the cathode 304, wherein a first low voltage is applied for a first period of time, wherein there is no electrical

communication between the second power supply 354 and the anode 314 and the plasma cathode 344. This first period of time is followed by a second period of time wherein no electrical communication is present between the first power supply 350, the anode 314 and the cathode 304, and no electrical communication is present between the second power supply 354 and the anode 314 and the plasma cathode 344. This second period of time is followed by a third period of time wherein an electrical connection is provided between the second power supply 354, the anode 314 and the plasma cathode 344, wherein there is no electrical communication between the first power supply 350 and the anode 314 and the cathode 304. This third period of time is followed by a fourth period of time wherein no electrical communication is present between the first power supply 350, the anode 314 and the cathode 304, and no electrical communication is present between the second power supply 354 and the anode 314 and the plasma cathode 344. The cycle then repeats.

[0083] In embodiments, the first period of time is greater than the second, third or fourth period of time. In embodiments, the first period of time is greater than or equal to about 1 millisecond, or greater than or equal to about 5 millisecond, or greater than or equal to about 10 milliseconds, or greater than or equal to about 100 milliseconds, or greater than or equal to about 500 milliseconds, and less than or equal to about 10 seconds, or 5 seconds, or 1 second.

[0084] In embodiments, the third period of time is greater than or equal to about 0.1 millisecond, or greater than or equal to about 0.5 millisecond, or greater than or equal to about 1 milliseconds, or greater than or equal to about 10 milliseconds, or greater than or equal to about 100 milliseconds, and less than or equal to about 1 second, or 0.5 seconds.

[0085] In embodiments, the second period and the fourth period of time are essentially equal. In embodiments, the second period and the fourth period of time are, independently, greater than or equal to about 0.1 millisecond, or greater than or equal to about 0.5 millisecond, or greater than or equal to about 1 milliseconds, or greater than or equal to about 10 milliseconds, or greater than or equal to about 100 milliseconds, and less than or equal to about 1 second, or 0.5 seconds.

[0086] In embodiments, a first duty cycle, calculated as the first period of time divided by the sum of the first, second, third and fourth periods of time, is greater than or equal to about 50%, or greater than or equal to about 65%, or greater than or equal to about 75%, or greater than or equal to about 90%.

[0087] In embodiments, a third duty cycle, calculated as the third period of time divided by the sum of the first, second, third and fourth periods of time, is greater than or equal to about 5%, and less than or equal to about 50%, or less than or equal to about 40%, or less than or equal to about 30%, or less than or equal to about 20%.

[0088] In embodiments, a second duty cycle, calculated as the second period of time divided by the sum of the first, second, third and fourth periods of time, is greater than or equal to about 0.5%, and less than or equal to about 20%, or less than or equal to about 15%, or less than or equal to about 10%, or less than or equal to about 5%.

[0089] In embodiments, a fourth duty cycle, calculated as the fourth period of time divided by the sum of the first, second, third and fourth periods of time, is greater than or equal to about 0.5%, and less than or equal to about 20%, or less than or equal to about 15%, or less than or equal to about 10%, or less than or equal to about 5%.

[0090] In embodiments, the plasma cathode comprises carbon, tungsten, a Group 8-11 metal, or a combination thereof. In embodiments, the anode and the cathode independently comprise carbon, a Group 8-11 metal, or a combination thereof. In embodiments, the anode and the cathode are a metal mesh, foam, or semi permeable metal frit.

[0091] In embodiments, at least a portion of the first chamber 370 i.e., the volume bound between the first outer plate 302 and the first semi-permeable divider 308, is irradiated with a first electromagnetic radiation 356 (only one of which is numbered for clarity) via a first electromagnetic radiation source 358. In embodiments, the first electromagnetic radiation 356 is provided through a transparent portion of the electrolytic cell 300, e.g., a transparent portion of the first outer plate 302 . As shown in FIG. 5, in other embodiments, one or more fiberoptic elements 500 are present within at least a portion of the first chamber 370 e.g., between the first outer plate 302 and the corresponding electrode e.g.,

cathode 304, and/or between the corresponding electrode e.g., cathode 304, and the first semi-permeable divider 308. The fiber optic element being in optical communication with the first electromagnetic radiation source 358. In embodiments, at least a portion of the first electromagnetic radiation source 358 may be present within the first chamber 370.

[0092] In embodiments, at least a portion of the second chamber 372 i.e., the volume bound between the second outer plate 312 and the first semi-permeable divider 308, is irradiated with a second electromagnetic radiation 362 (only one of which is numbered for clarity) via a second electromagnetic radiation source 360. In embodiments, the second electromagnetic radiation 362 is provided through a transparent portion of the electrolytic cell 300, e.g, a transparent portion of the second outer plate 312. In other embodiments, a fiberoptic is present within the second chamber 372 as described above for the first chamber 370 (See FIG. 5), wherein the fiberoptic is in optical communication with the second electromagnetic radiation source 360, and/or the second electromagnetic radiation source 360 is present within the second chamber 372.

[0093] In embodiments, the first electromagnetic radiation has a wavelength range from about 175 nm to about 525 nm. In embodiments, the first electromagnetic radiation has a wavelength greater than or equal to about 180 nm, or greater than or equal to about 200 nm, or greater than or equal to about 300 nm, and less than or equal to about 500 nm, or less than or equal to about 450 nm, or less than or equal to about 400 nm.

[0094] In embodiments, the wavelength of the first electromagnetic radiation is selected from a bright-line emission spectrum of hydrogen, wherein the wavelength is the center of the particular bright-line emission spectrum line of hydrogen +/- about 50 nm, or +/- about 20 nm, or +/- about 10 nm, or +/- about 5 nm, or +/- about 1 nm, or +/- about 0.1 nm. In embodiments, the wavelength of the first electromagnetic radiation is within the visible region, selected from the Balmer series, centered around 397 nm (i.e., from about 377 nm to about 427 nm), and/or centered around 410 nm (i.e., from about 390 nm to about 430 nm), and/or centered around 434 nm (i.e., from about 414 nm to about 454 nm), and/or centered around 486.1 nm (i.e., from about 466 nm to about 506 nm), and/or centered around 656.2 nm (i.e., from about 636 nm to about 676 nm).

[0095] In embodiments, the wavelength of the first electromagnetic radiation is selected from the Paschen series, e.g., 820.4 nm, 954.6 nm, 1005 nm, 1094 nm, 1282 nm, and/or 1875 nm plus or minus from about 1 to about 20 nm.

[0096] In embodiments, the wavelength of the first electromagnetic radiation is selected from the Lyman series, e.g., 91 nm, 94 nm, 95 nm, 97 nm, 103 nm, and/or 122 nm plus or minus from about 0.1 to about 20 nm.

[0097] In embodiments, the wavelength of the first electromagnetic radiation is selected from the Brackett series, e.g., 1458 nm, 1817 nm, 1944 nm, 2166 nm, 2625 nm, and/or 4051 nm, plus or minus from about 0.1 to about 20 nm.

[0098] In embodiments, the wavelength of the first electromagnetic radiation is selected from the Humphreys series, and/or the Pfund series according to values known in the art.

[0099] In embodiments, the second electromagnetic radiation has a wavelength range from about 550 nm to about 900 nm. In embodiments, the first electromagnetic radiation has a wavelength greater than or equal to about 600 nm, or greater than or equal to about 625 nm, or greater than or equal to about 690 nm, and less than or equal to about 800 nm, or less than or equal to about 750 nm, or less than or equal to about 700 nm.

[00100] In embodiments, the wavelength of the second electromagnetic radiation is selected from a bright-line emission spectrum of oxygen, wherein the wavelength is the center of the particular bright-line emission spectrum line of oxygen +/- about 50 nm, or +/- about 20 nm, or +/- about 10 nm, or +/- about 5 nm, or +/- about 1 nm, or +/- about 0.1 nm.

[00101] In embodiments, the wavelength of the second electromagnetic radiation is within the visible region, selected from bright line emission spectra centered around 391 nm, 395 nm, 398 nm, 407 nm, 412 nm, 420 nm, 432 nm, 441 nm, 460 nm, 471 nm, 616 nm, 646 nm, 700 nm, 725 nm, and/or 778 nm plus or minus from about 0.1 to about 20 nm.

[00102] In embodiments, the wavelength of the second electromagnetic radiation is within the UV region, selected from bright line emission spectra centered around 43 nm, 54 nm, 72 nm, 80 nm, 83 nm, 130 nm, 245 nm, 273 nm, 297 nm, 314 nm, 330 nm, 347 nm, and/or 373 nm plus or minus from about 0.1 to about 20 nm.

[00103] In embodiments, the wavelength of the second electromagnetic radiation is within the infrared region, selected from bright line emission spectra centered around 822 nm, 845 nm, 926 nm, 1129 nm, 1246 nm, 1257 nm, 1316 nm, 1802 nm, and/or 1824 nm, plus or minus from about 0.1 to about 20 nm.

[00104] In embodiments, at least one source of electromagnetic radiation is a spin-isolated monochromatic electromagnetic beam consisting essentially of a plurality of spin-isolated photons, wherein the spin-isolated photons are only observable within a plurality of first discrete ranges along a path of the monochromatic electromagnetic beam, each of the first discrete ranges centered at a corresponding distance from a source of the monochromatic electromagnetic beam, wherein essentially no photons are observable within a plurality of second discrete ranges located in-between each of the first discrete ranges as disclosed in US Patent Application no. XXXXXXXXXXXXX

[00105] As shown in the overhead view of FIG. 4, in embodiments, the electrolytic cell 300 is disposed within an external magnetic field source 400 configured to provide a magnetic field 406 between two magnetic poles e.g., a north pole 408 and a south pole 410 of a magnet or a plurality of magnets, oriented and arranged such that the magnetic field 406 flows through at least a portion of the first chamber 370, the second chamber 372, or both. As shown in FIG. 4, in embodiments, the electrolytic cell 300 is disposed between a north and a south pole of two magnets 402 and 404 such that at least a portion of the electrolytic cell 300 is disposed within a magnetic field 406 between the two poles of the magnets 402 and 404. In embodiments, the magnets are permanent magnets. In embodiments, the magnets are electromagnets. In embodiments, a strength of the magnetic field 406 is adjustable by moving the magnets relative to one another, adjusting an electric current/voltage to the magnets 402 and 404 wherein electromagnets are employed.

[00106] In embodiments, the poles of the magnets 402 and 404 are disposed and arranged such that a center line 412 extending between a center of each of the two magnetic poles is oriented at an angle 414 from about 2° to about 90° relative to a line 416 extending between a center of the cathode 418, through the first semi-permeable divider 420 to a

center of the anode 422. As shown in FIG. 4, the position of the two magnetic poles may be independently arranged 424 and 426.

[00107] FIG. 6 is a block diagram depicting an electrolytic hydrolysis cell for hydrolysis of water facilitated by electromagnetic radiation 600, wherein the perturbing of the bonding electrons between the hydrogen and oxygen atoms via interaction with electromagnetic radiation enhances the separation of hydrogen proton 610 from an oxygen atom 612 of a water molecule. In embodiments, photons (indicated by arrow 602) from irradiation of the first chamber 370 from the first electromagnetic radiation source 358 interact 604 with a target electron (606) to cause the poles of target electron 606 to change orientation (flip) thereby creating a force which disrupts the atomic B-field, dislodging (arrow 608) the target electron 606 out of the bonding position between the hydrogen proton 610 and the oxygen atom 612. The interaction 604 results in the formation of a proton 610(H+) and an OH- 614. The proton 610 is attracted to the cathode 304 e.g., negative electrode, and the hydroxyl anion 614 is attracted to the anode 314 (e.g., the positive electrode, through the first semi-permeable divider 308.

[00108] The cathodic radial electrostatic forces (rES) (616) from the cathode 304 pulls the proton 610, and the anodic rES 618 from the anode 314 pulls the OH- 614 towards the anode 314.

[00109] FIG. 7 depicts the interaction of the second electromagnetic radiation within the second chamber wherein bonding electrons present within hydroxyl anions are perturbed via interaction with electromagnetic radiation to facilitate the formation of oxygen. Photons 702 from the second electromagnetic radiation source 360 interact 704 with a target electron 706 as described above, ejecting 708 the target electron 706 associated with the bond between the first oxygen atom 710 and the hydrogen proton 722.

[00110] Initially, a first oxygen 710 has surrounding electrons 712 and one of the target electrons 706 present at two positions which are filled. The other target electron position 714 is open (not filled). The photons 702 from the second electromagnetic radiation source 360 interact 704 with a target electron 706 as described above and eject 708 the target electron 706, an attraction 718 and 720 between the electrons of a second oxygen

atom 716 and the first oxygen atom 710 result in the formation of an oxygen-oxygen double bond forming oxygen gas at the positively charged anode.

[00111] As depicted in FIG. 8, in embodiments, the hydrolysis cell 800 comprises a cathode 802 disposed within a cathode chamber 804 separated from, and in fluid communication with, an intermediate chamber 806 through a first membrane 808, and an anode 810 disposed within an anode chamber 812 separated from, and in fluid communication with, the intermediate chamber 806 through a second membrane 814. The cathode 802 in wired electrical communication with the anode 810 through a first external electrical power source (not shown). In embodiments, the hydrolysis cell 800 further includes a first electromagnetic radiation source 358 configured to irradiate at least a portion of the cathode chamber 804 at a first wavelength range suitable to increase production of hydrogen gas during electrolytic hydrolysis under the electrolytic hydrolysis conditions to a second rate of hydrogen gas production efficiency which is greater than the first rate of hydrogen gas production efficiency and at a greater efficiency than standard electrolysis practices.

[00112] In embodiments, the hydrolysis cell 800 further includes a second electromagnetic radiation source 360 configured to irradiate at least a portion of the anode chamber 812 at a second wavelength range suitable to increase production of gas production from the cell during electrolytic hydrolysis under the electrolytic hydrolysis conditions, thereby increasing the rate of hydrogen gas production efficiency to a third rate, which is greater than the first rate of hydrogen gas production efficiency.

[00113] In embodiments, the hydrolysis cell 800 further includes a third source of electromagnetic radiation 816 configured to irradiate at least a portion of the intermediate chamber 806 at a third wavelength range, which may be equal to the first and or the second wavelength range, selected to increase production of gas production from the cell during electrolytic hydrolysis under the electrolytic hydrolysis conditions, thereby increasing the rate of hydrogen gas production efficiency to a fourth rate, which is greater than the first rate of hydrogen gas production efficiency.

[00114] As depicted in FIG. 9, in embodiments, a hydrolysis cell 900 may include an porous intermediate chamber 902, configured as a porous barrier disposed between the first membrane 808 and the second membrane 814.

[00115] While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof.

Claims

1. An electrolysis cell comprising:

a first chamber separated from, and in fluid communication with a second chamber through a first semi-permeable divider;

a cathode disposed within the first chamber in wired electrical communication with an anode disposed within the second chamber through a first DC power supply;

the electrolysis cell configured to produce a first rate of hydrogen gas production efficiency within the first chamber when an aqueous electrolyte is present within the first and second chambers and an electrical potential is applied between the anode and the cathode under electrolytic hydrolysis conditions;

a first source of electromagnetic radiation configured to irradiate at least a portion of the first chamber at a first wavelength range suitable to increase a rate of hydrogen gas production efficiency during electrolytic hydrolysis under the electrolytic hydrolysis conditions to a rate of hydrogen gas production efficiency which is greater than the first rate of hydrogen gas production efficiency.

2. The electrolysis cell of claim 1, wherein the first wavelength range is plus or minus about 50 nm of an emission line produced from a hydrogen emission spectrum.

3. The electrolysis cell of claim 2, wherein the first wavelength range is from about 606 nm to about 706 nm.

4. The electrolysis cell of claim 1, further comprising a second source of electromagnetic radiation configured to irradiate at least a portion of the second chamber at a second wavelength range suitable to increase production of hydrogen gas during electrolytic hydrolysis under the electrolytic hydrolysis conditions to a rate of hydrogen gas production efficiency which is greater than the first rate of hydrogen gas production efficiency.

5. The electrolysis cell of claim 4, wherein the second wavelength range is about plus or minus 50 nm of an emission line produced from an oxygen emission spectrum.

6. The electrolysis cell of claim 5, wherein the second wavelength range is from about 347 nm to about 447 nm.

7. The electrolysis cell of claim 1, wherein the first semi-permeable divider is selectively permeability to protons; or
wherein the first semi-permeable divider is selectively permeability to hydroxyls ions.

8. The electrolysis cell of claim 1, wherein the first semi-permeable divider has a porosity of less than or equal to about 100 microns.

9. The electrolysis cell of claim 1, further comprising an external magnetic field source configured to provide a magnetic field between two magnetic poles through at least a portion of the first chamber, the second chamber, or both, wherein the two magnetic poles are arranged such that a line extending between a center of each of the two magnetic poles is oriented at an angle from about 2° to about 90° relative to a line extending between a center of the cathode, through the first semi-permeable divider to a center of the anode.

10. The electrolysis cell of claim 1, wherein an outer face of the cathode is spaced away from a first chamber wall by a first distance, and an inner face of the cathode is spaced away from the first semi-permeable divider by a second distance, an outer face of the anode is spaced away from a second chamber wall by a third first distance, and an inner face of the anode is spaced away from the first semi-permeable divider by a fourth distance;
wherein a first electrolyte is pumped through a cathode inlet into contact with the cathode through the first distance and the second distance and out of the electrolysis cell through a cathode outlet;

wherein a second electrolyte is pumped through an anode inlet into contact with the anode through the third distance and the fourth distance and out of the electrolysis cell through an anode outlet;
wherein the first distance, the second distance, the third distance, and the fourth distance are independently greater than or equal to about 0.5 mm;
and wherein a distance between the inner face of the cathode and an inner face of the anode is less than or equal to about 10 mm.

11. The electrolysis cell of claim 1, further comprising a plasma cathode in electrical communication with a second DC power supply in wired electrical communication between the anode and the plasma cathode, the second DC power supply configured to provide a voltage potential between the anode and the plasma cathode sufficient to produce a plasma under the hydrolysis conditions.

12. The electrolysis cell of claim 11, configured to provide a repeating pulsed voltage cycle comprising:
providing a low voltage pulse potential from the first DC power supply between the cathode and the anode for a first period of time; followed by
a first rest period of time wherein no potential is applied between the cathode and the anode, or between plasma cathode and the anode; followed by
a plasma voltage pulse potential from the second DC power supply between the plasma cathode and the anode for a second period of time;
followed by a second rest period of time wherein no potential is applied between the anode and the cathode or the plasma cathode;
wherein the cycle repeats.

13. The electrolysis cell of claim 12, wherein the first period of time is greater than each of the second period of time, the first rest period of time, and the second rest period of time; and/or
wherein the first rest period of time is essentially equal to the second rest period of time.

14. The electrolysis cell of claim 12, wherein during the first rest period of time and the second rest period of time, the anode and the cathode are electrically isolated from the first DC power supply and the anode and the plasma cathode are electrically isolated from the second DC power supply;
wherein during the first period of time, the anode and the plasma cathode are electrically isolated from the second DC power supply;
wherein during the second period of time, the anode and the cathode are electrically isolated from the first DC power supply;
or a combination thereof.

15. An electrolysis cell comprising:
a cathode chamber comprising a cathode disposed therein, separated from, and in fluid communication with an intermediate chamber through a first membrane;
an anode chamber comprising an anode disposed therein, separated from, and in fluid communication with the intermediate chamber through a second membrane;
wherein the cathode is in wired electrical communication with the anode through a first DC power supply;
wherein the first membrane is selectively permeable to protons and the second membrane is selectively permeable to hydroxyl ions;
the electrolysis cell configured to produce a first rate of hydrogen gas production efficiency within the first chamber when an aqueous electrolyte is present within the cathode chamber, the intermediate chamber, and the anode chamber and an electrical potential is applied between the anode and the cathode under electrolytic hydrolysis conditions; and
a first source of electromagnetic radiation configured to irradiate at least a portion of the cathode chamber at a first wavelength range suitable to increase production of hydrogen gas during electrolytic hydrolysis under the electrolytic hydrolysis conditions to a rate of hydrogen gas production efficiency which is greater than the first rate of hydrogen gas production efficiency.

16. The electrolysis cell of claim 15, further comprising a second source of electromagnetic radiation configured to irradiate at least a portion of the anode chamber at a second wavelength range suitable to increase production of hydrogen gas during electrolytic hydrolysis under the electrolytic hydrolysis conditions to a rate of hydrogen gas production efficiency which is greater than the first rate of hydrogen gas production efficiency.

17. The electrolysis cell of claim 15, further comprising a third source of electromagnetic radiation configured to irradiate at least a portion of the intermediate chamber at a third wavelength range suitable to increase production of hydrogen gas during electrolytic hydrolysis under the electrolytic hydrolysis conditions to a rate of hydrogen gas production efficiency which is greater than the first rate of hydrogen gas production efficiency.

18. A method to produce hydrogen gas comprising:
directing a first electrolyte stream into a first chamber of an electrolysis cell comprising a cathode disposed within the first chamber;
directing a second electrolyte stream into a second chamber of the electrolysis cell comprising an anode disposed within the second chamber;
wherein the first chamber is separated from, and in fluid communication with the second chamber through a first semi-permeable divider;
applying a first DC electrical current to the cathode and the anode at a temperature and at a potential sufficient to produce hydrogen from the cathode; and
irradiating at least a portion of the first chamber with electromagnetic radiation at a first wavelength range to produce hydrogen from the cathode.

19. The method of claim 18, further comprising applying an external magnetic field between two magnetic poles through at least a portion of the first chamber, the second chamber, or both, wherein the two magnetic poles are arranged such that a line extending between a center of each of the two magnetic poles is oriented at an angle from about 2°

to about 90° relative to a line extending between a center of the cathode, through the first semi-permeable divider to a center of the anode.

20. The method of claim 19, further comprising applying a second DC electrical current between a plasma cathode and the anode at a potential sufficient to produce a plasma within the first electrolyte, wherein the first DC electrical current and the second DC electrical current are provided in a repeating pulsed voltage cycle comprising:
providing the first DC electrical current as a pulse between the cathode and the anode for a first period of time; followed by
a first rest period of time wherein no potential is applied between the cathode and the anode, or between the plasma cathode and the anode; followed by
providing the second DC electrical current as a pulse between the plasma cathode and the anode for a second period of time; followed by
a second rest period of time wherein no potential is applied between the cathode and the anode, or between the plasma cathode and the anode;
wherein the cycle repeats.

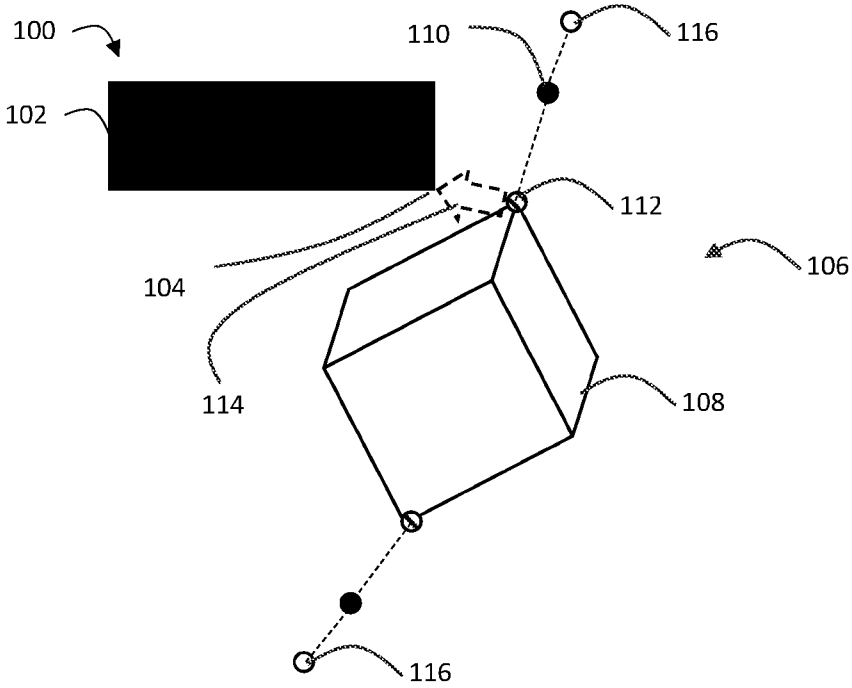

FIG. 1

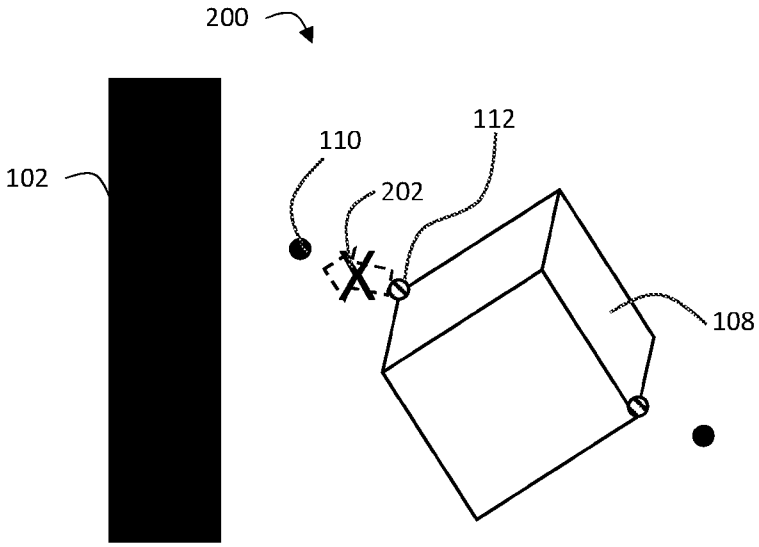

FIG. 2

FIG. 3

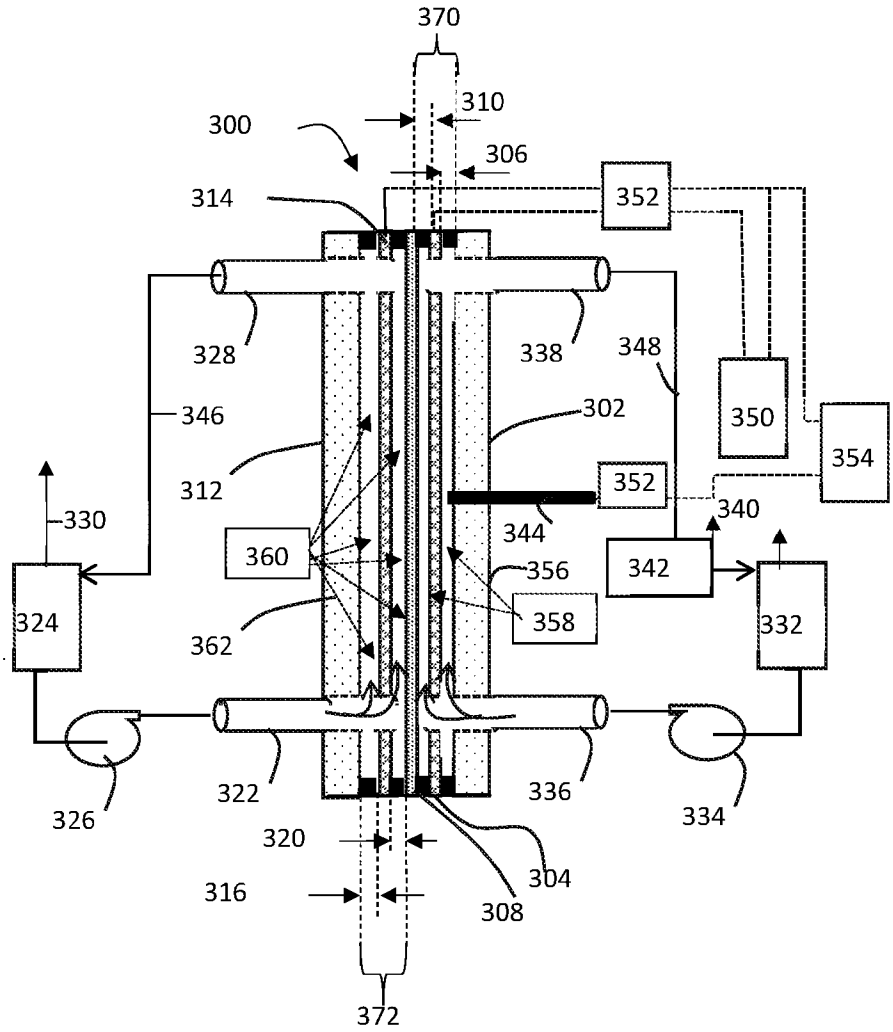
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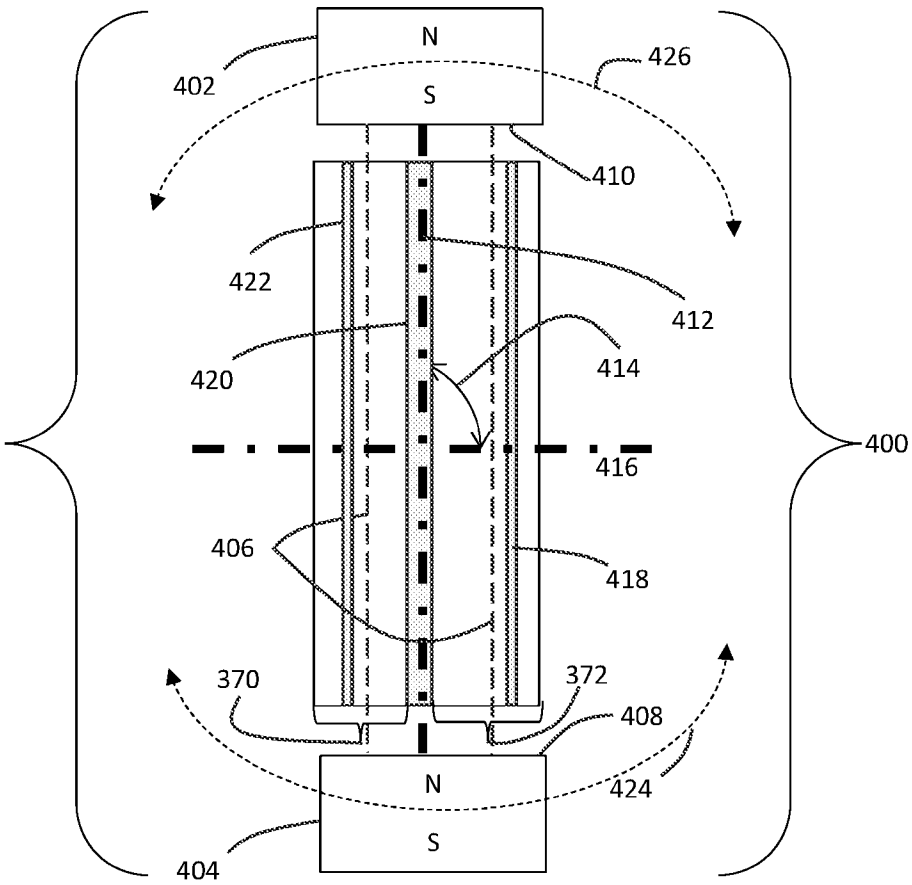
FIG. 4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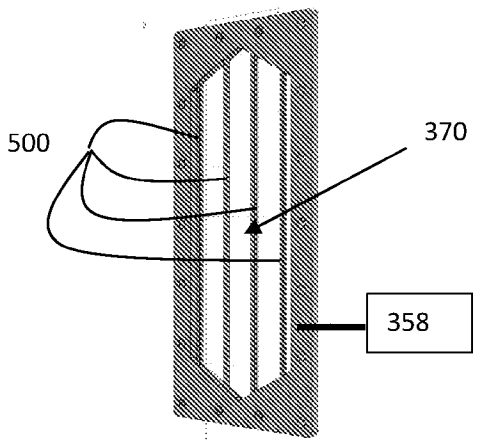
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FIG. 5

FIG. 6

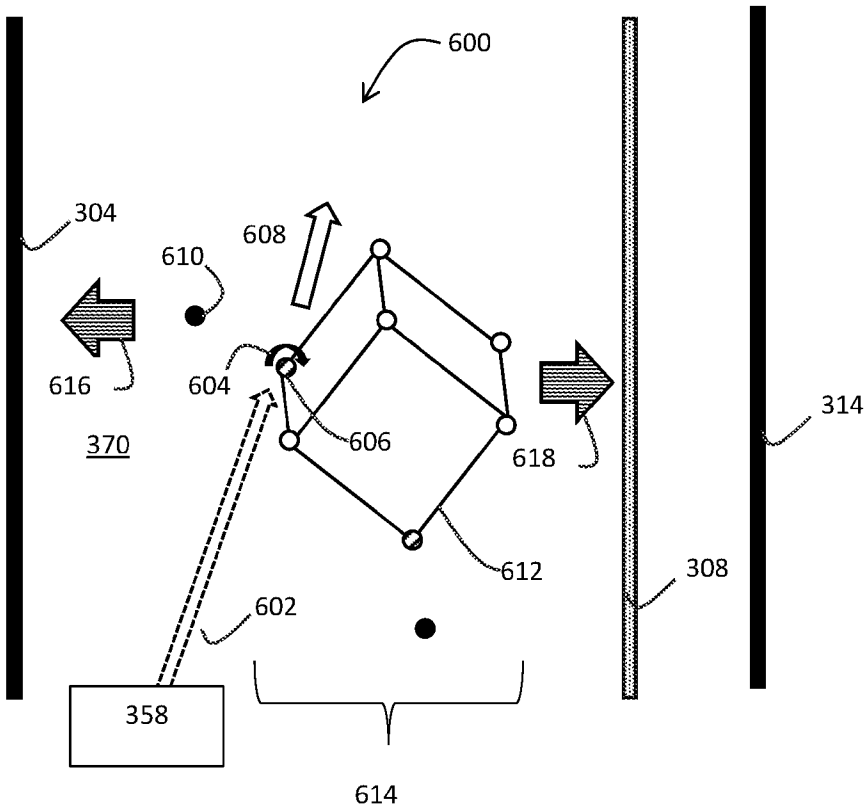
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FIG. 7

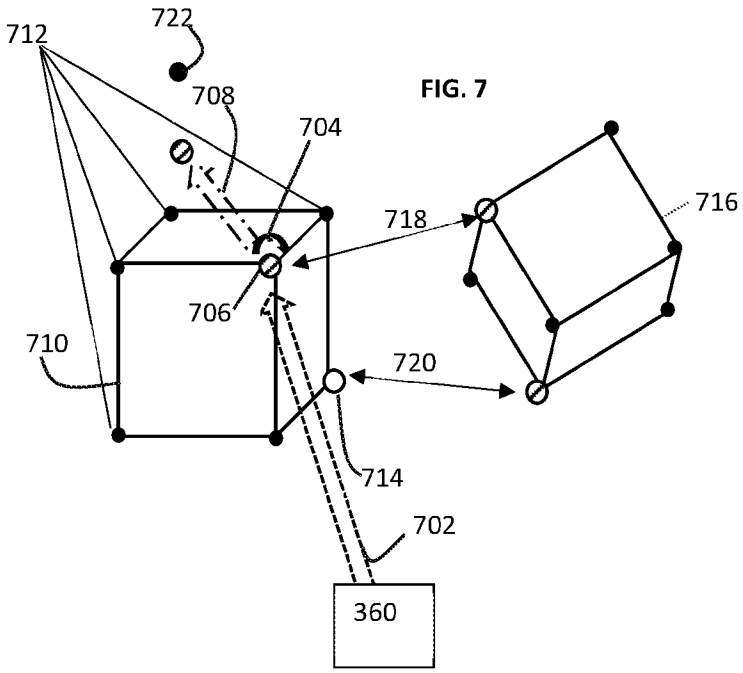
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FIG. 8

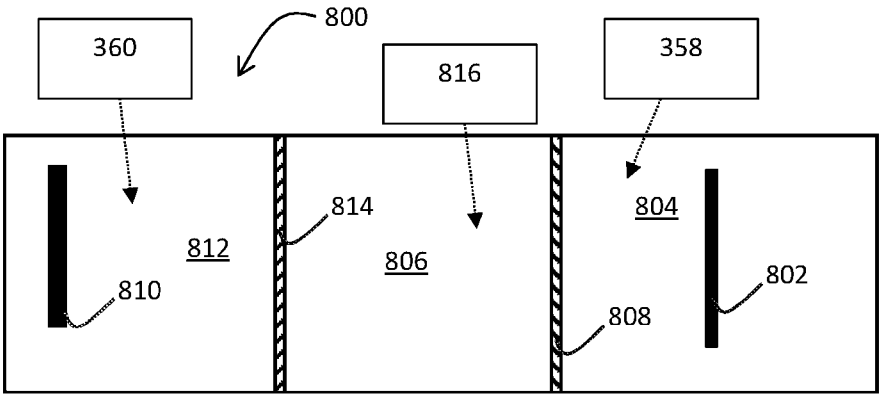
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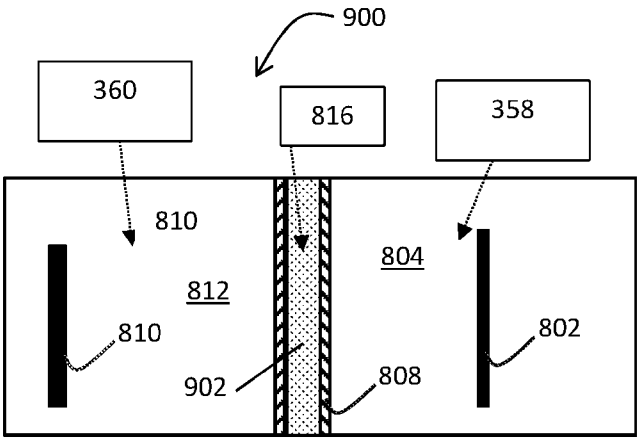
FIG. 9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