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ENERGY STORAGE DEVICES.

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The present disclosure concerns energy storage devices,
more specifically electrochemical devices for storage of
energy which are based on reverse chloro-alkali process.

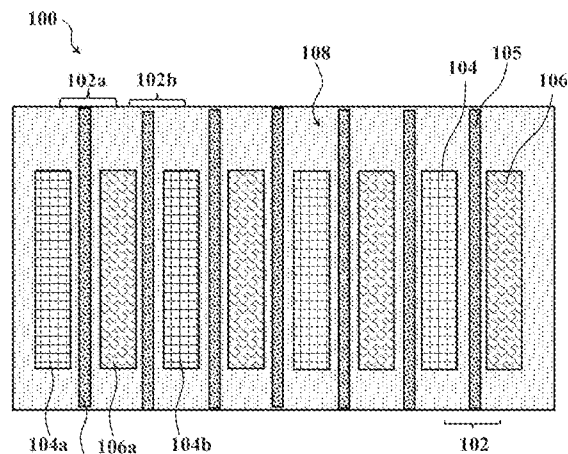


Fig. 1A

ENERGY STORAGE DEVICES

TECHNOLOGICAL FIELD

The present disclosure concerns energy storage devices, more specifically electrochemical devices for storage of energy.

BACKGROUND ART

References considered to be relevant as background to the presently disclosed subject matter are listed below:

- US patent application publication no. 2019/386348
- US patent publication no. 10,415,143
- US patent publication no. 4,311,771
- US patent application publication no. 2014/072836
- US patent application publication no. 2021/013551

Acknowledgement of the above references herein is not to be inferred as meaning that these are in any way relevant to the patentability of the presently disclosed subject matter.

BACKGROUND

Storage of energy in a readily usable form has been the focus of many efforts in the past few decades. With the increase of demand for readily-available energy and increasing interest in renewable energy sources and storage, several energy storage devices have been developed, for example lead-acid batteries, lithium ions batteries, nickel-iron batteries, *etc.* These devices are based on an electrochemical reaction, typically redox reactions, taking place in an electrolytic medium present between two electrodes (a cathode and an anode), generating electrically charged species (ions and electrons).

Charging and discharging of typical electrochemical cells are based oppositely-directed oxidation and reduction processes. For example, in lithium-ion batteries, an

oxidation half-reaction at the anode produces positively charged lithium ions and negatively charged electrons during discharge, lithium ions move through the electrolyte, electrons move through an external circuit, and then they recombine at the cathode (together with the cathode material) in a reduction half-reaction. The electrolyte and external circuit function to conduct lithium ions and electrons, but do not partake in the electrochemical reaction. During charging these reactions and transports are reversed - electrons move from the positive electrode to the negative electrode through the external circuit, a process which requires provision of energy from an external source. This energy is then stored as chemical energy in the cell.

While lithium-ion batteries are gaining more popularity, these are often problematic for manufacture and application due to toxic or non-environmentally friendly materials, as well as the relatively high cost of raw materials. In addition, lithium-ion batteries are known for their unstable re-charging, reducing robustness of such batteries.

Other types of electrochemical cells which are based on more environmentally friendly materials, such as aluminum batteries, chlorine-oxygen or hydrogen-oxygen fuel cells, *etc.*, often require utilization of complex and expensive catalytic materials and/or working temperatures which are relatively high, currently making their use more limited.

There is therefore an ongoing need for energy storage devices which are based on relatively common and inexpensive raw materials, that can provide a high number of working cycles (*i.e.* charging-discharging cycles), that can be used as readily-available energy sources, as well as more reliable and safer to use.

GENERAL DESCRIPTION

The present disclosure provides energy storage devices which are electrically stable and rechargeable for a high number of charging-discharging cycles compared to other rechargeable chemical batteries known up to date. The energy storage devices of this disclosure are based on the understanding that energy can be stored as potential chemical energy utilizing relatively large concentration of charge carriers, together with efficient charge conductivity through the device can be obtained from combinations of relatively simple and safe raw materials.

Thus, in one of its aspects, the disclosure provides an energy storage device comprising at least one electrochemical unit submerged in an electrolytic solution. The device is substantially gas tight, as to maintain all gaseous products formed during operation of the device within the unit, as will be further explained below. The electrochemical unit comprises at least two electrically chargeable plates, a polymer electrolyte membrane, a conductive medium and said electrolyte solution. Each of the at least two electrically chargeable plates is in contact with a current collector element, with the polymer electrolyte membrane disposed between the two electrically chargeable plates. The at least two electrically chargeable plates sandwich between them the conductive medium, which comprises a porous conductive matrix loaded with at least one conductive hydrogel composition, and at least one gas physisorbing material. The electrolytic solution is a saturated solution of one or more metal salts.

When the electrically chargeable plates are charged in opposite electrical charges, electrolysis of the metal salts in the electrolytic solution is obtained, causing accumulation of electrolysis products adjacent the plates and subsequent redox reactions to obtain electrically-neutral gaseous products. The gaseous products are entrapped within the conductive medium by various mechanism, as will be explained below, as remain stable as long as the polarity of the plates is not reversed. Thus, the electrical energy invested into the device during charging is stored within the device in the form of potential chemical energy, thereby electrically charging the device. When the polarity of the plates is reversed, *i.e.* when an electrical circuit is reclosed between the plates via a system or an appliance that requires utilization of the stored energy, the potential difference between the plates causes the gaseous products to ionize (*i.e.* reverse the redox reactions), permitting chemical recombination of the ionic species, causing release of the stored energy and flow of electrons through the circuit, and hence energy for operating the appliance or system to which the device is connected.

The devices of this disclosure are rich in charge carriers or potential charge carriers, as saturated solutions of salts are used. By some embodiments, the electrolytic solution a super-saturated electrolytic solution of said one or more metal salts.

The device is also gas-tight (*i.e.* sealed), as to prevent the gaseous species formed in the charging process from escaping the device and prevent reduction in concentration of gaseous species that may affect the overall efficiency of the discharging process. In

other words, by sealing the device, the gases that are formed as products in the electrolysis process during charging of the devices are maintained in the device and serve as raw materials for the chemical recombination process that occurs during discharging of the devices.

Further, the devices of this disclosure, as will be further elaborated below, provides for effective collection and transport of electrons, due to the structure of the conductive medium. Due to its structure, the conductive medium also enables entrapping the redox reactions gaseous products and stabilizing them after charging of the device, while permitting their release at the discharging phase of the device. In other words, utilization of saturated (or super-saturated) salt solutions permits formation of charge carriers in a high concentration, while the structure of the conductive medium allows for both separation and stabilization of the electrolysis products in the charging stage for storage of energy in the system in the form of potential chemical energy, and efficient electron collection at the discharging stage when the electrolysis products are chemically recombined.

The conductive medium, as noted above, comprises a porous conductive matrix that is loaded (or packed) with at least one conductive hydrogel composition, and at least one gas physisorbing material. Owing to its large surface area, the porous conductive matrix, together with the conductive hydrogel composition, provide for effective charge transfer from the electrodes to the electrolyte during the charging stage, and effective charge transfer to the current collectors at the discharging stage.

The term *porous conductive matrix* refers to a three-dimensional (3D) structure made out of one or more electrically conductive materials that is constructed as an open cellular structure containing pores that are connected to one another and form an interconnected network. The porous conductive matrix herein has a dual function. One the one hand, the porous matrix serves as a mechanical scaffold, mechanically holding and/or reinforcing the conductive hydrogel and gas physisorbing material, while on the other hand its large surface area, 3-D structure and conductivity permit effective transfer of charge to the hydrogel and electrolyte solution during charging and discharging.

According to some embodiments, the porous conductive matrix is a fibrous matrix, which can comprise woven or non-woven fibers. By some embodiments, the porous conductive matrix is a non-woven fibrous matrix.

In some embodiments, the fibrous matrix is selected from carbon felt, graphite felt, and polyacrylonitrile graphite felt, or a combination thereof. By some embodiments, the porous conductive matrix comprises polyacrylonitrile graphite felt.

The porous conductive matrix is loaded (or packed) with a mixture said conductive hydrogel composition, and at least one gas physisorbing material. The *conductive hydrogel composition* refers to a composition of one or more electrically conductive polymers which are water absorbing polymers that form a gel structure. The one or more polymers are typically cross-linked hydrophilic polymers, that are capable of absorbing and holding water molecules within the network of the polymeric molecules, however without dissolving in the water. Thus, the hydrogel maintains its physical stability while also being capable of holding and stabilizing large amounts of water. In the devices of this disclosure, the hydrogel composition holds the electrolyte solution, which is typically an aqueous saturated solution of one or more salts.

The hydrogel is a conductive hydrogel, meaning that the hydrogel comprises at least one electrically conductive polymeric material. The conductive medium is designed such that the conductive hydrogel is saturated by the electrolyte. Due to its conductivity, the hydrogel is capable of transfer charge to the electrolyte during charging, and transferring charge formed during recombination of the electrolysis products during discharging of the device to the porous conductive matrix. Further, due to its gel structure and high viscosity, the hydrogel is capable of physically entrapping at least a portion of the electrolysis products in the form of gaseous species, thereby preventing their discharge from the conductive medium during charging and while the device is charged and not in use. The hydrogel also functions to isolate and separate the entrapped redox gaseous products from other electrolysis products in the system, thus stabilizing the system between charging and discharging cycles.

In some embodiments, the hydrogel composition comprises one or more super-absorbing polymer (SAP) materials. The term *super absorbent polymer material* refers to a polymer (typically a cross-linked polymer) or a polymer composition, that can absorb and retain large quantities of liquids, such as water (or liquids containing water), relative to the dry mass of the polymer. It is preferable that the super absorbing polymer material be an ionic (or semi-ionic) super absorbing polymer material, namely comprise one or

more types of ions in order to permit charge transfer therethrough when electrical potential difference is applied between the plates.

The term *polymer* includes homopolymers, copolymers, such as for example, block, graft, random and alternating copolymers as well as terpolymers, further including their derivatives, combinations and blends thereof. In addition to the above the term includes all geometrical configurations of such structures including linear, block, graft, random, alternating, branched structures, and combination thereof. The term *block copolymer* is meant to encompass a polymeric material formed from two or more homo-polymer subunits (blocks) linearly linked by chemical bonds (*i.e.* the blocks are connected end-to-end). Block copolymers with two, three, four and multiple homo-polymer units are referred to as di-block, tri-block, tetra-blocks and multi-blocks respectively. The number of monomer types in a block co-polymer may be less than or equal to the number of blocks. Thus, an ABC linear tri-block consists of three monomer types, whereas an ABA linear tri-block consists of two monomer types.

In some embodiments, the SAP can be an anionic polymer or a cationic polymer, such that the SAP contains one or more ions permitting the SAP to become electrically conductive when a potential difference is applied between the electrically chargeable plates. In some other embodiments, the SAP can be selected from one or more of polyacrylates, polymethylmethacrylates, alginates, sulfonated polymers, polyacrylamides, polyvinyl alcohols, and any combination or copolymer thereof.

By some embodiments, the SAP can be selected from sodium polyacrylate, potassium polyacrylate, sodium alginate, potassium alginate, polyacrylamide, polystyrene sulfonate, and any combinations or copolymers thereof.

According to some embodiments, the one or more super-absorbing polymer materials comprises a mixture of sodium polyacrylate and potassium polyacrylate. By such embodiments, the mixture of super-absorbing polymer materials can comprise at least 15 wt% sodium polyacrylate. By other embodiments, the mixture of super-absorbing polymer materials can comprise between about 15 wt% and 50 wt% sodium polyacrylate. According to some embodiments, the mixture of super-absorbing polymer materials can comprise at most 85 wt% potassium polyacrylate. By other embodiments, the mixture of super-absorbing polymer materials can comprise between about 45 wt% and 85 wt% sodium polyacrylate. According to other embodiments, the mixture can comprise between

about 15 wt% and about 50 wt% of sodium polyacrylate and between about 50 wt% and 85 wt% of potassium polyacrylate.

As noted, in the devices of this disclosure, the SAP is in the form of a hydrogel. Hence, by some embodiments, the hydrogel composition can comprise up to about 85 wt% of water, *e.g.* ranging between about 15 and about 85 wt% of water. The water typically participates in the electrolysis process when charging the device, to form charged species within the electrolytic solution.

By some embodiments, the hydrogel has electrical conductivity of between about 50 mS/cm and about 500 mS/cm.

As noted, the conductive medium also comprises at least one gas physisorbing material, as noted above, that is selected to physisorb the gaseous products, *e.g.* H₂, during the charging stage, while capable of releasing the gaseous products by desorption at the discharge stage to permit their re-ionization and chemical recombination, as described above and will be further elaborated herein.

The term *physisorb* means to denote physical reversible adsorption of gas bubbles onto the surface of a material. Hence, the *gas physisorbing material* is a material or a composition of matter that reversibly adsorbs the gaseous species formed in the electrolysis process and the subsequent redox reactions – the gaseous species, which are products of the electrolysis process of said electrolyte solution, are adsorbed onto the surface of the gas physisorbing material during charging of the device, where these remain stably absorbed until reversal of polarity of the plates and discharging of the device. Once disrobed, the gaseous species can undergo re-ionization and recombination and release the chemical energy stored therein.

In some embodiments, the at least one gas physisorbing material is selected from inorganic carbon-based compounds, zeolites, metal oxides, and combinations thereof.

By some embodiments, the at least one gas physisorbing material is an inorganic carbon-based additive, selected from graphitic carbon nitride, exfoliated graphite, expanded exfoliated graphite, graphene, carbon nanotubes, and combinations thereof.

According to some embodiments, the at least one gas physisorbing is a hydrogen physisorbing material, namely, is capable of physisorbing at least H₂ gas molecules.

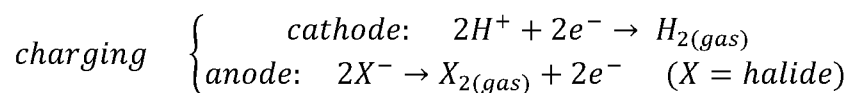
As the device is typically a closed system, the electrochemical and chemical reactions can be reversed again in order to re-charge the device and store energy therein.

It is of note, that the conductive medium is sandwiched between the electrically conductive plates; for obtaining such a configuration, the conductive medium can be contained in a volume defined between the plates, or the plates can be submerged within the conductive medium that is wetted or soaked by the electrolyte solution.

The *electrolytic solution* means to denote a liquid phase in which the sandwich of plates and conductive medium are submerged, that typically comprises a saturated aqueous solution of one or more metal salts. The metal salts can be fully dissolved in the electrolytic solution or can be dispersed therein. By some embodiments, the electrolytic solution is a super-saturated electrolytic solution of the one or more metal salts.

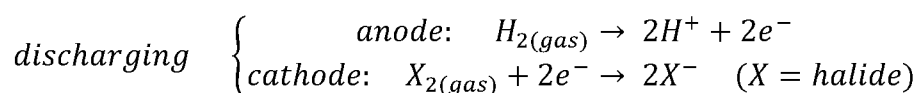
The one or more metal salts, by some embodiments, are selected from metal halides, metal sulfates, metal phosphates, metal nitrates, metal hydroxides, metal carbonates, metal oxy-hydrates, *etc.* By some embodiments, the metal salts are metal halides, *i.e.* metal chlorides, metal fluorides, metal iodides, and/or metal bromides. The metal salts are typically selected from water soluble salts and can, by some embodiments, be selected from sodium chloride (NaCl), potassium chloride (KCl), aluminum chloride (AlCl₃), calcium chloride (CaCl₂), magnesium chloride (MgCl₂), titanium chloride (TiCl₃), lithium chloride (LiCl), zinc chloride (ZnCl₂), nickel (II) chloride (NiCl₂), iron (II) chloride (FeCl₂), iron (III) chloride (FeCl₃), sodium aluminate (NaAlO₂), potassium aluminate (KAlO₂) and mixtures and/or hydrates thereof.

As noted, the metal salts undergo electrolysis (and/or dissolution in the case of highly-soluble salts), to form charge carriers within the electrolyte solution. During charging the charge carriers undergo reduction-oxidation reactions (redox), forming electrically neutral gaseous products, according to the following equations:



The gaseous products are, as noted, entrapped within the hydrogel (e.g. the halide gas) and/or adsorbed onto the gas physisorbing material (e.g. the hydrogen gas), until the polarity of the plates is reversed. Once polarity is reversed in order to discharge the device, e.g. by connecting the device to a system for utilization of the energy stored therein, the gaseous products undergo redox reaction to obtain the charge carriers. The

protons are permitted to migrate through the membrane, thereby enabling their re-combination with the halide ions, returning the device into a re-chargeable state:



As a person of the art may appreciate, other reactions between electrolysis products can be obtained as well, e.g. with other cations (for example the metal cations) or anions (for example hydroxyls) that may be obtained in the electrolysis process. Further, the same principle is applicable also for metal oxides and/or metal hydroxides, in which oxygen can be obtained as a gaseous product (instead or in addition to the halide).

The utilization of a conductive porous matrix and the conductive hydrogel enable efficient electron transfer in both the charging and discharging stages. Further, as the re-combination reaction in the discharging stage is typically exothermic, the high surface area of the conductive porous matrix also enables quick and efficient dissipation of heat, reducing the overall heating of the device. Hence, utilization of the redox reactions of the electrolysis products permits storing energy in the form of potential chemical energy, and readily utilization thereof.

Due to the structure of the conductive medium, the gaseous products of the charging stage are maintained within the device, without the need to accumulate these in designated external containers, which, in turn, significantly reducing the size of the device and eliminating the need for complicated gas-collection and/or flowing equipment.

Thus, according to some embodiment the device is a gas-tight system or is housed or encased within a gas-tight system, minimizing and/or preventing gas leakage out of the conductive medium.

According to some embodiments, the electrolytic solution comprises at least 20 wt%, at least 22 wt%, at least 25 wt%, at least 30 wt%, or even at least 35 wt% of said one or more metal salts. According to other embodiments, the electrolytic solution comprises at least about 0.1M of said one or more metal salts, e.g. between about 0.1M and about 8M of said one or more metal salts.

According to some embodiments, the electrolyte solution comprises a deep eutectic solvent, saturated or super-saturated with said one or more salts. A *deep eutectic solvent* is a mixture of two or more compounds, typically containing ionic species, that when mixed, the mixture is characterized by a melting temperature that is significantly lower than the melting temperature of each of the compounds alone. In some embodiments, the deep eutectic solvent has a melting temperature that is below about 40°C.

According to some embodiments, the deep eutectic solvent comprises at least one first component that can be one or more hydrogen bond acceptors, typically quaternary ammonium salts, and at least one second component that can be selected from one or more of a metal halide, a metal halide hydrate, and a hydrogen bond donor. According to some other embodiments, the deep eutectic solvent comprises at least one quaternary ammonium salt and at least one hydrogen bond donor.

By some embodiments, the at least one quaternary ammonium salt is a halide quaternary ammonium salt; for example the quaternary ammonium salt can be selected from choline chloride, tetramethylammonium chloride (TMACl), tetrapropylammonium bromide (TPMBr), N-ethyl-2-hydroxy-N,N-dimethylethanaminium chloride, 2-(chlorocarbonyloxy)-N,N,N-trimethylethanaminium chloride, N-benzyl-2-hydroxy-N,N-dimethylethanaminium chloride, tetrabutylammonium chloride, tetrabutylammonium trifluoromethanesulfonate, and mixtures thereof. By other embodiments, the at least one quaternary ammonium salt is choline chloride.

As noted, the deep eutectic solvent is formed, by some embodiments, when the quaternary ammonium salt is mixed with a hydrogen bond donor. The *hydrogen bond donor* is a molecule that can supply a hydrogen atom to another molecule (or a lone pair of electrons) when reacted with said other molecule. Without wishing to be bound by theory, the interaction between the quaternary ammonium salt and the metal salt, metal halide or the hydrogen bond donor often results in complexation. The charge delocalization occurring through hydrogen bonding during complexation results in charge hindrance for crystallization, therefore reducing the melting temperature of the mixture as compared to the individual melting temperatures of each of the mixtures' components.

Due to their relatively high electrochemical stability, the deep eutectic solvent can be used to increase the conductive medium's electrical conductivity, thereby assisting in

charge transfer during charging and discharging of the device between the conductive hydrogel and the porous conductive matrix.

According to some embodiments, the at least one hydrogen bond donor is selected from urea, polyethylene glycol, glycerin, polypropylene glycol, acetamide, 1-methyl urea, 1,3-dimethyl urea, 1,1-dimethyl urea, thiourea, benzamide, oxalic acid, glycerol, benzoic acid, malonic acid, adipic acid, citric acid, succinic acid, succinonitrile, and mixtures thereof.

According to some embodiments, the eutectic solvent comprises choline chloride and ethylene glycol.

As noted above, the electrochemical unit comprises at least two electrically chargeable plates. The plates can be identical to one another or different from one another in terms of any one of composition, geometry, surface and/or surface area. In some embodiments, all of the plates are made of the same material. In other embodiments, all of the plates have the same geometry and/or the same area, and/or the same surface area.

By other embodiments, all of the plates are identical (*i.e.* the electrochemical unit being formed between the plates is a symmetrical unit).

By other embodiments, the at least two electrically chargeable plates in a unit are different from one another by at least one parameter selected from composition, geometry, size, area, and surface area. When the plates differ one from the other, an asymmetrical electrochemical unit is formed.

By some embodiments, the electrically chargeable plates are each independently made of a material selected from aluminum and aluminum alloys, magnesium and magnesium alloys, zinc and zinc alloys, stainless steel, nickel and nickel alloys, silver and silver alloys, gold and gold alloys, copper and copper alloys, graphite and doped graphite (for example graphite doped with boron, nitrogen, phosphorous, etc.), graphene and doped graphene (*e.g.* doped with nitrogen, boron, sulfur, fluorine, transitions metals, oxides of transition metals, *etc.*).

The electrically chargeable plates are typically selected as to withstand corrosive conditions developing in the electrolyte solution due to the electrolysis process. Hence, when the electrically chargeable plate is made of corrodible material under the conditions of operation of the device, the plates are treated for corrosion protection. For example, the plates can be coated by a non-corroding coating, such as gold coating, silver coating,

graphite coating, graphene coating, activated carbon coating, *etc.* Alternatively, or additionally, the plates can be treated by impregnation (*e.g.* fluorination) to increase their resistance to corrosive conditions.

Alternatively, each of the plates can be a bipolar plate. In other words, each of the plates can have a first chargeable face and a second, opposite chargeable face, that can each be oppositely charged. Such a bipolar plate thus has one face positively charged, and the other being negatively charged. Such difference in charging can be obtained, for example, by coating the two faces of the bipolar plate by different coatings.

The plates, by some embodiments, can be made of, or coated by, a material functioning as catalytic surfaces for reducing the activation energy of the electrolytic chemical processes. According to some embodiments, each of the plates can be made of, or coated by, a material independently selected from titanium and titanium alloys, ruthenium and ruthenium alloys, tantalum and tantalum alloys, iridium and iridium alloys, platinum and platinum alloys, carbonaceous materials (such as graphite, graphene, glassy carbon and carbon nanotubes), and others.

The plates can be of any size or shape. By some embodiments, the plates are substantially continuous solid masses, *e.g.* substantially continuous non-porous slabs, sheets or films. By other embodiments, the plates can be porous. By yet other embodiments, the plates can be in the form of a mesh, a netting or a lattice.

Typically, the device comprises a plurality of electrochemical units, which may be arranged in various geometries with respect to one another. In some embodiments, the units are parallelly arranged. In other embodiments, the units are stacked one on top of the other. In yet other embodiments, the device may comprise two or more stacked layers of units, the units within each layer being parallelly arranged.

In some embodiments, the electrically chargeable plates in the device comprise a plurality of first electrically chargeable plates and a plurality of second electrically chargeable plates, alternately arranged in the device (such that parallel arrangement of units is formed), the first plates and the second plates being chargeable by opposite electrical charges. In such embodiments, adjacent electrochemical units share a common electrically chargeable plate.

Alternatively, the electrically chargeable plates can be bipolar plates, and each electrochemical unit is defined between a first chargeable face of one bipolar plate and a

second chargeable face of an adjacent bipolar plate, the first and second chargeable faces being oppositely chargeable.

In between the at least two electrically chargeable plates, as noted above, there is positioned a polymer electrolyte membrane. The polymer electrolyte membrane (PEM, also known as proton exchange membrane) is an electrically non-conductive membrane, semipermeable to permit transfer of protons (i.e. H^+). The PEM functions as an electronic insulator, as well as a barrier to gas species migration within the device (e.g. H_2 and Cl_2).

The polymer electrolyte membrane is made of at least one polymeric material, typically a hydrophobic polymer functionalized with hydrophilic functional groups, that can undergo hydration with water of the electrolytic solution and phase separation on the nanoscale to produce hydrophilic and hydrophobic domains. The hydrophobic domains are made-up of associated backbones of the polymeric molecules and provide mechanical strength to the membrane, while the hydrophilic domains contain water molecules that associate with the hydrophilic functional groups, as well as the dissociated ions, thereby permitting transport of the protons through the membrane.

The PEM can be made from a fluoropolymer (such as Nafion or Teflon) or polyaromatic polymers. The PEM can be carbon-supported or non-carbon supported.

The device can comprise one or more sensors configured to measure or provide indication of one or more parameters. Such sensors can, for example, be selected from pH sensors, oxidation-reduction potential (ORP) sensors, temperature sensors, conductivity sensors, turbidity sensors, liquid level sensors, flow sensors, multimeters (to measure the Ampere and Voltage), *etc.*

By another aspect, the disclosure provides an energy storage device comprising at least one electrochemical unit submerged in a saturated (or super-saturated) electrolytic solution of one or more water soluble halide metal salts, the device being substantially gas-tight and the electrochemical unit comprising: at least two electrically chargeable plates, each of which being in contact with a current collector element; a porous non-conductive membrane disposed between said at least two electrically chargeable plates; and a conductive medium sandwiched between said at least two electrically chargeable plates, the conductive medium comprising a fibrous conductive matrix loaded with at least one super-absorbing conducting hydrogel and at least one inorganic carbon-based hydrogen-absorbing additive.

By yet another aspect, the disclosure provides an energy storage device comprising at least one electrochemical unit submerged in a saturated (or super-saturated) electrolytic solution of one or more water soluble metal chloride salts, the device being substantially gas-tight and said electrochemical unit comprising: at least two electrically chargeable plates, each of which being in contact with a current collector element; a porous non-conductive membrane disposed between said at least two electrically chargeable plates; and a conductive medium sandwiched between said at least two electrically chargeable plates, the conductive medium comprising a fibrous polyacrylonitrile graphite felt conductive matrix loaded with at least one super-absorbing conducting hydrogel of at least one cationic polyacrylate, and at least one inorganic carbon-based hydrogen-absorbing additive.

By another aspect, there is provided an energy storage array (*e.g.* a battery pack) that comprises two or more devices according to this disclosure. The energy storage array can be configured for storage and utilization of energy in various systems. For example, each of the devices in the array can be connected to a system for utilization of energy in a sequential manner (*i.e.* each device in the array is discharged separately, one after the other, when utilizing the array). Alternatively, the array can be electrically connection to a system that utilizes variable amounts of energy, such that the devices can discharge energy proportional to the specific or variable energy consumption of the system.

The array can be gas-tight (*i.e.* sealed). Preferably, each device within the array is sealed or gas-tight, thereby maintaining the gaseous products formed during charging entrapped and/or contained within the conductive medium.

Each of the devices, or the array of devices, can be utilized for storing energy generated by a renewable energy source, such as solar arrays, wind turbines, hydroelectric facilities, biogas, water wave energy, *etc.* The devices, or the array of devices, can be utilized for providing energy to various systems, such as industrial facilities, municipal electric grid, electrically or hybrid-operated vehicles, *etc.*

The array can be configured to readily attach and detach to the system in which it is utilized, for ease of installation and replacement. Alternatively, the array can be fixedly attached to the system in which it is utilized, and each of the energy storage devices in the array can be readily detachably attached to the electrical infrastructure within the array, such that individual devices can be readily replaced when needed.

A method for storing energy in a device of the kind described herein is also an aspect of this disclosure. The method comprises storing energy in a device described herein by oppositely electrically charging said at least two electrically chargeable plates to introduce energy into the device and electrolyze said one or more metal salts and water in said saturated electrolytic solution to obtain electrical charge carriers; and permitting, during said electrically charging, said electrical charge carriers to combine into electrically-neutral gas molecules, entrapped within said conductive medium, thereby storing said energy in said device and the device being substantially gas tight as to maintain the gas molecules within the device.

A method of obtaining energy from the storage device described herein is also an aspect of the present disclosure. Thus, the disclosure also provides a method of obtaining energy from the storage device disclosed herein, the method comprises charging the device as described herein; reversing the polarity in said at least two oppositely-charged electrically chargeable plates to permit desorption of said gas molecules from said conductive medium; and permitting said gas molecules to react therebetween, thereby releasing energy in the form of electrons, the electrons being transferred from the solution to the current collectors via conductive medium.

According to some embodiments, during charging of the device, electrolysis products in the form of gas molecules are entrapped within the conductive hydrogel and physisorbed onto the at least one gas physisorbing material.

By some embodiments, said one or more salts are selected from sodium chloride, potassium chloride, aluminum chloride, calcium chloride, magnesium chloride, titanium chloride, lithium chloride, zinc chloride, nickel (II) chloride, iron (II) chloride, iron (III) chloride, and any mixture and/or hydrate thereof, and said gas molecules are hydrogen (H_2) and chlorine (Cl_2).

By another one of its aspects, the present disclosure provides use of a device for producing energy from hydrogen gas and chlorine gas, the device comprising at least one electrochemical unit submerged in an electrolytic solution, and said electrochemical unit comprising:

a first inlet for introducing hydrogen gas into the device and a second inlet for introducing chlorine gas into the device,

at least two electrically chargeable plates, each of which being in contact with a current collector element,

a polymer electrolyte membrane disposed between said at least two electrically chargeable plates, and

a conductive medium sandwiched between said at least two electrically chargeable plates, the conductive medium comprising a porous conductive matrix loaded with at least one conductive hydrogel composition and at least one gas physisorbing material configured for absorbing at least one of the hydrogen and chlorine gases,

the electrolytic solution being a saturated electrolytic solution of one or more metal halide salts,

the device being sealed as to prevent gaseous species to leak out of the device.

By another one of its aspects, the present disclosure provides use of a device for producing energy from gas molecules, the device comprising at least one electrochemical unit submerged in an electrolytic solution, and said electrochemical unit comprising:

a first inlet for introducing a first gas into the device and a second inlet for introducing a second gas into the device,

at least two electrically chargeable plates, each of which being in contact with a current collector element,

a polymer electrolyte membrane disposed between said at least two electrically chargeable plates, and

a conductive medium sandwiched between said at least two electrically chargeable plates, the conductive medium comprising a porous conductive matrix loaded with at least one conductive hydrogel composition and at least one gas physisorbing material configured for absorbing at least one of the first and second gases,

the electrolytic solution being a saturated electrolytic solution of one or more metal salts,

the device being sealed as to prevent gaseous species to leak out of the device.

As used herein, the term *about* is meant to encompass deviation of $\pm 10\%$ from the specifically mentioned value of a parameter, such as temperature, pressure, concentration, etc.

Whenever a numerical range is indicated herein, it is meant to include any cited numeral (fractional or integral) within the indicated range. The phrases *ranging/ranges between* a first indicate number and a second indicate number and "ranging/ranges from" a first indicate number "to" a second indicate number are used herein interchangeably and are meant to include the first and second indicated numbers and all the fractional and integral numerals therebetween.

If not specifically defined otherwise, all concentrations, pH values, conductivity, viscosity, etc. refer to values measured at room temperature, typically about 23-25°C, and atmospheric pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to better understand the subject matter that is disclosed herein and to exemplify how it may be carried out in practice, embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1A is a schematic representation of an exemplary device according to this disclosure, using pairs of positively-charged and negatively-charged plates.

Fig. 1B is a schematic representation of the conductive medium.

Fig. 2 is a schematic representation of an exemplary device according to this disclosure, using an array of bipolar plates.

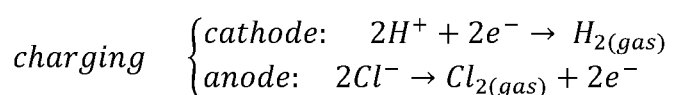
DETAILED DESCRIPTION OF EMBODIMENTS

As noted, the energy storage devices are based on the capability to chemically store energy within the device in a stable manner, permitting to then chemically recombine the electrolysis products in order to utilize the stored energy. In the devices of this disclosure, relatively large concentration of charge carriers is formed during charging of the device, that are combined into non-charged, chemically stable species, hence permitting stable storage of potential energy for prolonged periods of time, while also

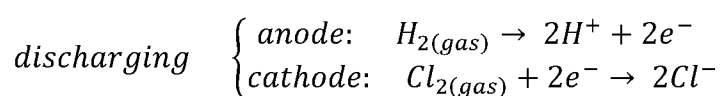
providing efficient charge conductivity through the device when the electrolysis species obtained during charging are allowed to recombine.

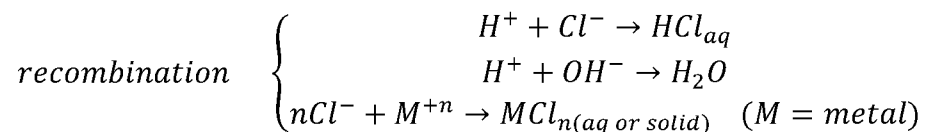
In the energy storage device, at least one electrochemical unit is submerged in an electrolytic solution, which is a saturated, typically super-saturated, solution of one or more metal salts, typically water-soluble metal salts. A conductive medium is located between the two plates (or, alternatively, the plates are surrounded by the conductive medium), that is designed for efficient charge transfer between the plates and the electrolytic solution in the charging stage, as well as for efficient electron collection and transportation from the medium to the plates (or current collectors) in the discharging stage.

An exemplary device of this disclosure comprises a super-saturated aqueous solution of one or more metal halide salts, for example one or more metal chloride salts. In this example, 2 half-cells of a redox reaction are formed. During charging, protons undergo reduction at the cathode to produce hydrogen gas (H_2), which is then physisorbed onto the gas-physisorbing material, while the chloride ions undergo oxidation at the anode to obtain chlorine gas. The chlorine gas can be absorbed onto the gas physisorbing material and/or entrapped within the viscous hydrogel.



Once the device is attached to a system for utilizing the energy stored therein, the polarity of the plates is reversed, and the gaseous products undergo redox reactions to obtain the charge carriers. The protons are permitted to migrate through the membrane, thereby permitting their re-combination with the chloride ions and other electrolysis ionic species (e.g. the metal ions or hydroxyls formed during electrolysis of water), returning the device into a re-chargeable state:





In a sense, when metal chloride salts are utilized, the charging stage can be looked at as a form of the chloro-alkali process, while the discharging and recombination stage can be looked at as a form of reverse chloro-alkali process.

The utilization of a conductive porous matrix and the conductive hydrogel enable efficient electron transfer in both the charging and discharging stages. Further, as the recombination reaction in the discharging stage is typically exothermic, the high surface area of the conductive porous matrix also enables quick and efficient dissipation of heat, reducing the overall heating of the device. Hence, utilization of the redox reactions of the electrolysis products permits storing energy in the form of potential chemical energy, and readily utilization thereof.

Due to the structure of the conductive medium, the gaseous products, e.g. H₂ and Cl₂, are maintained within the device, without the need to accumulate these in designated external containers, which, in turn, significantly reducing the size of the device and eliminating the need for complicated gas-collection and/or flowing equipment. Further, additional confinement of the gaseous products within the device is afforded by sealing the device in a substantially gas-tight manner, thereby maintaining the gaseous products produced during operation within the device to increase its overall efficiency.

A schematic representation of an embodiment of a device according to this disclosure is shown in Fig. 1A. The device **100**, comprises a plurality of electrochemical units, generally designated **102**, each including a pair of oppositely charged plates **104** and **106**. The plates **104** and **106** are submerged in a conductive medium, generally designated **108** that is soaked with or submerged in an electrolytic solution, being a saturated or super-saturated solution of one or more metal salts. While in the exemplified device of Fig. 1A, the conductive medium and the electrolytic solution form an environment in which the plates are submerged, hence resulting in an arrangement in which the conductive medium soaked surrounds the plates (and hence a volume thereof is sandwiched between the plates), it is to be understood that the conductive medium **108**

can be confined to the space formed between each two plates **104** and **106**, and being submerged in the electrolytic solution (which forms a continuous environment).

Polymer electrolyte membranes (PEM) **105** are positioned between the plates, permitting transport of protons therethrough, however preventing transport of other charge carriers, thereby functioning as charge separators.

The conductive medium **108**, as schematically shown in Fig. 1B, comprises a porous, typically fibrous, conductive matrix **110**, that is loaded (or packed) with a mixture of a conductive hydrogel composition and one or more gas-physisorbing materials **112**, and is soaked with the electrolyte solution. In other words, mixture **112** at least partially fills the porous structure (or the space between the fibers) of the conductive matrix **110**. The electrolyte solution is at least partially held within the swollen structure of the hydrogel. Due to its large surface area and 3D structure, the conductive matrix **110** forms an efficient conductor of electrons during charging and discharging, while also assisting dissipation of heat that may be formed within the device during charging and/or discharging. Further effective charge transfer is permitted through the conductive hydrogel in mixture **112**. Thus, the conductive medium functions to effectively transfer the charges to and from the electrolyte solution during charging and discharging, respectively.

In the exemplified device of Fig. 1A, the plates are alternatingly arranged, i.e. two adjacent units **102** share a common plate which is oppositely charged than the others. For example, adjacent units **102a** and **102b** share a common charged plate **106a** while the other plates **104a** and **104b** are charged oppositely to plate **106a**. Such an arrangement enables to include a larger number of adjacent units in a given device volume. However, it is also contemplated that each unit will include two oppositely charged plates **104** and **106**, without a common plate.

When charging the device, plates **104** and **106** are oppositely charged, thereby causing one or more electrolytic reactions in the electrolytic solution, providing electrolysis products, i.e. ionized species, in relatively high concentration, followed by the redox reactions described above to obtain stable gaseous products that are embedded in the hydrogel and/or adsorbed onto the gas-physisorbing material. When the plates are not connected to one another by an external circuit (*i.e.* not charged), the membrane and hydrogel composition substantially behaves as an electrical insulator, providing effective

separation between the gaseous products, thereby maintaining the potential chemical energy stored in the device, resulting in a stable energy storage device. When the device is connected to a system or an appliance that requires the energy stored therein, change in polarity causes desorption of the gaseous products from the hydrogel and the gas-physisorbing material, and permit their migration towards the plates to be reduced/oxidized for re-obtaining a high density of ionic species. Effective charge transfer is provided due to the properties of the hydrogel composition and the structure of the conductive matrix. As the device is typically a closed system, the electrochemical and redox reactions can be reversed again in order to re-charge the device and store energy therein.

Another embodiment is exemplified in Fig. 2. The arrangement of Fig. 2 is similar to that of Fig. 1A, however each of the plates in the device is a bipolar plate. Bipolar plates **120** each have a first chargeable face **124** and a second chargeable face **126**, that are oppositely charged. Hence, the electrochemical unit **102** is formed, in the example of Fig. 2, between face **124a** of plate **120i** and oppositely charged face **126b** of adjacent plate **120ii**.

CLAIMS:

1. An energy storage device comprising at least one electrochemical unit submerged in an electrolytic solution, the energy storage device being substantially gas tight and said electrochemical unit comprising

at least two electrically chargeable plates, each of which being in contact with a current collector element,

a polymer electrolyte membrane disposed between said at least two electrically chargeable plates, and

a conductive medium sandwiched between said at least two electrically chargeable plates, the conductive medium comprising a porous conductive matrix loaded with at least one conductive hydrogel composition and at least one gas physisorbing material,

the electrolytic solution being a saturated electrolytic solution of one or more metal salts.

2. The device of claim 1, wherein said porous conductive matrix is a fibrous matrix.

3. The device of claim 2, wherein said fibrous matrix comprises woven or non-woven fibers.

4. The device of claim 2 or 3, wherein said fibrous matrix is selected from carbon felt, graphite felt, and polyacrylonitrile graphite felt, and combinations thereof.

5. The device of claim 1, wherein said porous conductive matrix comprises polyacrylonitrile graphite felt.

6. The device of any one of claims 1 to 5, wherein the conductive hydrogel composition comprising one or more super-absorbing polymer materials.

7. The device of any one of claims 1 or 6, wherein the conductive hydrogel composition comprises one or more ionic super-absorbing polymer materials.

8. The device of claim 7, wherein the super-absorbing polymer material is selected from one or more of sodium polyacrylate, potassium polyacrylate, sodium alginate, potassium alginate, polyacrylamides, polystyrene sulfonate, polyvinyl alcohols, and any combination thereof.

9. The device of any one of claims 6 to 8, wherein the one or more super-absorbing polymer materials comprise a mixture of sodium polyacrylate and potassium polyacrylate.

10. The device of claim 9, wherein said mixture comprises at least about 15 wt% sodium polyacrylate.
11. The device of claim 9 or 10, wherein said mixture comprises at most about 85 wt% potassium polyacrylate.
12. The device of any one of claims 9 to 11, wherein the said mixture comprises between about 15 wt% and about 50 wt% of sodium polyacrylate and between about 50 wt% and 85 wt% of potassium polyacrylate.
13. The device of any one of claims 1 or 12, wherein the conductive hydrogel composition comprises up to about 85 wt% of water.
14. The device of any one of claims 1 to 13, wherein said at least one gas physisorbing material is selected from inorganic carbon-based compounds, zeolites, metal oxides, and combinations thereof.
15. The device of claim 14, wherein said at least one gas physisorbing material is an inorganic carbon-based additive, selected from graphitic carbon nitride, exfoliated graphite, expanded exfoliated graphite, graphene, carbon nanotubes, and combinations thereof.
16. The device of claim 14 or 15, wherein said at least one gas physisorbing is a hydrogen physisorbing material.
17. The device of any one of claims 1 to 16, wherein said electrolytic solution is a super-saturated electrolytic solution of said one or more metal salts.
18. The device of any one of claims 1 to 17, wherein said one or more metal salts are selected from metal halides, metal sulfates, metal phosphates, metal nitrates, metal hydroxides, metal carbonates, and metal oxy-hydrates.
19. The device of any one of claims 1 to 18, wherein said one or more metal salts are selected from sodium chloride, potassium chloride, aluminum chloride, calcium chloride, magnesium chloride, titanium chloride, lithium chloride, zinc chloride, nickel (II) chloride, iron (II) chloride, iron (III) chloride, sodium aluminate, potassium aluminate, and any mixture and/or hydrate thereof.
20. The device of any one of claims 1 to 19, wherein the electrolytic solution comprises a deep eutectic solvent.
21. The device of claim 20, wherein said deep eutectic solvent comprises at least one first component being one or more quaternary ammonium salt and at least one second

component being selected from one or more of a metal halide, a metal chloride halide, and a hydrogen bond donor.

22. The device of claim 20 or 21, wherein, said deep eutectic solvent comprises at least one quaternary ammonium salt and at least one hydrogen bond donor.

23. The device of claim 22, wherein said at least one quaternary ammonium salt is selected from choline chloride, tetramethylammonium chloride (TMACl), tetrapropylammonium bromide (TPMBr), N-ethyl-2-hydroxy-N,N-dimethylethanaminium chloride, 2-(chlorocarbonyloxy)-N,N,N-trimethylethanaminium chloride, N-benzyl-2-hydroxy-N,N-dimethylethanaminium chloride, tetrabutylammonium chloride, tetrabutylammonium trifluoromethanesulfonate, and any mixture thereof.

24. The device of claim 22 or 23, wherein said at least one hydrogen bond donor is selected from urea, polyethylene glycol, glycerin, polypropylene glycol, acetamide, 1-methyl urea, 1,3-dimethyl urea, 1,1-dimethyl urea, thiourea, benzamide, oxalic acid, glycerol, benzoic acid, malonic acid, adipic acid, citric acid, succinic acid, succinonitrile, and any mixture thereof.

25. The device of any one of claims 1 to 24, wherein said electrically chargeable plates are each made of at least one conductive material selected from aluminum and aluminum alloys, magnesium and magnesium alloys, zinc and zinc alloys, stainless steel, nickel and nickel alloys, silver and silver alloys, gold and gold alloys, copper and copper alloys, graphite and doped graphite, graphene and doped graphene, carbon fiber, and carbon fiber composite.

26. The device of claim 25, wherein the electrically chargeable plates are made of carbon fiber or carbon fiber composite.

27. The device of claim 25 or 26, wherein the electrically charged plates are treated for corrosion protection.

28. The device of any one of claims 1 to 27, wherein each of said electrically chargeable plates is a bipolar plate.

29. The device of any one of claims 1 to 28, wherein the device comprises a plurality of said electrochemical units.

30. The device of claim 29, wherein the electrically chargeable plates comprise a plurality of first electrically chargeable plates and a plurality of second electrically

chargeable plates, alternately arranged in the device, the first plates and the second plates being chargeable by opposite electrical charges.

31. The device of claim 30, wherein adjacent electrochemical units share a common electrically chargeable plate.

32. The device of claim 31, wherein the electrically chargeable plates are bipolar plates, and each electrochemical unit is defined between a first chargeable face of one bipolar plate and a second chargeable face of an adjacent bipolar plate, the first and second chargeable faces being oppositely chargeable.

33. An energy storage device comprising at least one electrochemical unit submerged in a saturated electrolytic solution of one or more water soluble metal halide salts, the energy storage device being substantially gas tight and said electrochemical unit comprising

- at least two electrically chargeable plates, each of which being in contact with a current collector element,

- a porous non-conductive membrane disposed between said at least two electrically chargeable plates, and

- a conductive medium sandwiched between said at least two electrically chargeable plates, the conductive medium comprising a fibrous conductive matrix loaded with at least one super-absorbing conducting hydrogel and at least one inorganic carbon-based hydrogen-absorbing additive.

34. An energy storage device comprising at least one electrochemical unit submerged in a saturated electrolytic solution of one or more water soluble metal chloride salts, the energy storage device being substantially gas tight and said electrochemical unit comprising

- at least two electrically chargeable plates, each of which being in contact with a current collector element,

- a porous non-conductive membrane disposed between said at least two electrically chargeable plates, and

- a conductive medium sandwiched between said at least two electrically chargeable plates, the conductive medium comprising a fibrous conductive matrix selected from carbon felt, graphite felt, and polyacrylonitrile graphite felt, the fibrous conductive matrix being loaded with (i) at least one super-absorbing conducting hydrogel

that comprises a mixture of sodium polyacrylate and potassium polyacrylate, and (ii) at least one inorganic carbon-based hydrogen-absorbing additive selected from graphitic carbon nitride, exfoliated graphite, and expanded exfoliated graphite.

35. An energy storage array, comprising two or more devices according to any one of claims 1 to 34.

36. A method for storing energy in a device of any one of claims 1 to 34, comprising:
oppositely electrically charging said at least two electrically chargeable plates to introduce energy into the device and electrolyze said one or more metal salts and water in said saturated electrolytic solution to obtain electrical charge carriers, and

permitting, during said electrically charging, said electrical charge carriers to combine into electrically-neutral gas molecules, entrapped within said conductive medium, thereby storing said energy in said device, the device being substantially gas tight as to maintain the gas molecules within the device.

37. The method of claim 36, wherein said gas molecules are entrapped within the conductive hydrogel and physisorbed onto said at least one gas physisorbing material.

38. A method of obtaining energy from the storage device of any one of claims 1 to 34, comprising:

charging the device according to the method of claim 36 or 37; and

reversing the polarity in said at least two oppositely-charged electrically chargeable plates to permit desorption of said gas molecules from said conductive medium, and

permitting said gas molecules to react therebetween, thereby releasing energy in the form of electrons,

the electrons being transferred from the solution to the current collectors via conductive medium.

39. The method of any one of claims 36 to 38, wherein said one or more salts are selected from sodium chloride, potassium chloride, aluminum chloride, calcium chloride, magnesium chloride, titanium chloride, lithium chloride, zinc chloride, nickel (II) chloride, iron (II) chloride, iron (III) chloride, and any mixture and/or hydrate thereof.

40. The method of claim 39, wherein said gas molecules are hydrogen (H₂) and chlorine (Cl₂).

41. A device for use in producing energy from hydrogen gas and chlorine gas, the device comprising at least one electrochemical unit submerged in an electrolytic solution, and said electrochemical unit comprising:

a first inlet for introducing hydrogen gas into the device and a second inlet for introducing chlorine gas into the device,

at least two electrically chargeable plates, each of which being in contact with a current collector element,

a polymer electrolyte membrane disposed between said at least two electrically chargeable plates, and

a conductive medium sandwiched between said at least two electrically chargeable plates, the conductive medium comprising a porous conductive matrix loaded with at least one conductive hydrogel composition and at least one gas physisorbing material configured for absorbing at least one of the hydrogen and chlorine gases,

the electrolytic solution being a saturated electrolytic solution of one or more metal halide salts,

the device being sealed as to prevent gaseous species to leak out of the device.

42. A device for use in producing energy from gas molecules, the device comprising at least one electrochemical unit submerged in an electrolytic solution, and said electrochemical unit comprising:

a first inlet for introducing a first gas into the device and a second inlet for introducing a second gas into the device,

at least two electrically chargeable plates, each of which being in contact with a current collector element,

a polymer electrolyte membrane disposed between said at least two electrically chargeable plates, and

a conductive medium sandwiched between said at least two electrically chargeable plates, the conductive medium comprising a porous conductive matrix loaded with at least one conductive hydrogel composition and at least one gas physisorbing material configured for absorbing at least one of the first and second gases,

the electrolytic solution being a saturated electrolytic solution of one or more metal salts,

the device being sealed as to prevent gaseous species to leak out of the device.

ANSPRÜCHE:

1. Energiespeichervorrichtung mit mindestens einer elektrochemischen Einheit, die in eine elektrolytische Lösung eingetaucht ist, wobei die Energiespeichervorrichtung im Wesentlichen gasdicht ist und die elektrochemische Einheit Folgendes umfasst
 - mindestens zwei elektrisch aufladbare Platten, von denen jede in Kontakt mit einem Stromabnehmerelement steht,
 - eine Polymerelektrolytmembran, die zwischen den mindestens zwei elektrisch aufladbaren Platten angeordnet ist, und
 - ein leitfähiges Medium, das sandwichartig zwischen den mindestens zwei elektrisch aufladbaren Platten angeordnet ist, wobei das leitfähige Medium eine poröse leitfähige Matrix umfasst, die mit mindestens einer leitfähigen Hydrogelzusammensetzung und mindestens einem gas- physisorbierenden Material beladen ist,
 - die elektrolytische Lösung ist eine gesättigte elektrolytische Lösung eines oder mehrerer Metallsalze .
2. Vorrichtung nach Anspruch 1, wobei die poröse leitfähige Matrix eine faserige Matrix ist.
3. Vorrichtung nach Anspruch 2, wobei die faserige Matrix gewebte oder nicht gewebte Fasern umfasst.
4. Vorrichtung nach Anspruch 2 oder 3, wobei die faserige Matrix ausgewählt ist aus Kohlenstofffilz, Graphitfilz und Polyacrylnitrilgraphitfilz und Kombinationen davon.
5. Vorrichtung nach Anspruch 1, wobei die poröse leitfähige Matrix Polyacrylnitrilgraphitfilz umfasst.
6. Vorrichtung nach einem der Ansprüche 1 bis 5, wobei die leitfähige Hydrogelzusammensetzung ein oder mehrere superabsorbierende Polymermaterialien umfasst.
7. Vorrichtung nach einem der Ansprüche 1 oder 6, wobei die leitfähige Hydrogelzusammensetzung ein oder mehrere ionische superabsorbierende Polymermaterialien umfasst.

8. Vorrichtung nach Anspruch 7, wobei das superabsorbierende Polymermaterial aus einem oder mehreren von Natriumpolyacrylat, Kaliumpolyacrylat, Natriumalginat, Kaliumalginat, Polyacrylamiden, Polystyrolsulfonat, Polyvinylalkoholen und einer beliebigen Kombination davon ausgewählt ist.
9. Die Vorrichtung nach einem der Ansprüche 6 bis 8, wobei das eine oder die mehreren superabsorbierenden Polymermaterialien eine Mischung aus Natriumpolyacrylat und Kaliumpolyacrylat umfassen.
10. Vorrichtung nach Anspruch 9, wobei die Mischung mindestens etwa 15 Gew.-% Natriumpolyacrylat enthält.
11. Vorrichtung nach Anspruch 9 oder 10, wobei die Mischung höchstens etwa 85 Gew.-% Kaliumpolyacrylat enthält.
12. Vorrichtung nach einem der Ansprüche 9 bis 11, wobei die Mischung zwischen etwa 15 Gew.-% und etwa 50 Gew.-% Natriumpolyacrylat und zwischen etwa 50 Gew.-% und 85 Gew.-% Kaliumpolyacrylat enthält.
13. Vorrichtung nach einem der Ansprüche 1 oder 12, wobei die leitfähige Hydrogelzusammensetzung bis zu etwa 85 Gew.-% Wasser enthält.
14. Vorrichtung nach einem der Ansprüche 1 bis 13, wobei das mindestens eine gasphysisorbierende Material ausgewählt ist aus anorganischen Verbindungen auf Kohlenstoffbasis, Zeolithen, Metalloxiden und Kombinationen davon.
15. Vorrichtung nach Anspruch 14, wobei das mindestens eine gasphysiobierende Material ein anorganisches Additiv auf Kohlenstoffbasis ist, das aus graphitischem Kohlenstoffnitrid, Blähgraphit, expandiertem Blähgraphit, Graphen, Kohlenstoffnanoröhren und Kombinationen davon ausgewählt ist.
16. Vorrichtung nach Anspruch 14 oder 15, wobei das mindestens eine gasphysisorbierende ein wasserstoffphysisorbierendes Material ist.
17. Vorrichtung nach einem der Ansprüche 1 bis 16, wobei die elektrolytische Lösung eine übersättigte elektrolytische Lösung des einen oder der mehreren Metallsalze ist.
18. Vorrichtung nach einem der Ansprüche 1 bis 17, wobei das eine oder die mehreren Metallsalze ausgewählt sind aus Metallhalogeniden, Metallsulfaten, Metallphosphaten, Metallnitraten, Metallhydroxiden, Metallcarbonaten und Metalloxydhydraten.

- 19.** Vorrichtung nach einem der Ansprüche 1 bis 18, wobei das eine oder die mehreren Metallsalze ausgewählt sind aus Natriumchlorid, Kaliumchlorid, Aluminiumchlorid, Calciumchlorid, Magnesiumchlorid, Titanchlorid, Lithiumchlorid, Zinkchlorid, Nickel(II)-chlorid, Eisen(II)-chlorid, Eisen(III)-chlorid, Natriumaluminat, Kaliumaluminat und jeder Mischung und/oder jedem Hydrat davon.
- 20.** Vorrichtung nach einem der Ansprüche 1 bis 19, wobei die elektrolytische Lösung ein tief eutektisches Lösungsmittel umfasst.
- 21.** Vorrichtung nach Anspruch 20, wobei das tief eutektische Lösungsmittel mindestens eine erste Komponente umfasst, bei der es sich um ein oder mehrere quaternäre Ammoniumsalze handelt, und mindestens eine zweite Komponente, die aus einem oder mehreren Metallhalogenid(en), Metallchloridhalogenid(en) und einem Wasserstoffbindungsdonator ausgewählt ist.
- 22.** Vorrichtung nach Anspruch 20 oder 21, wobei das tief eutektische Lösungsmittel mindestens ein quaternäres Ammoniumsalz und mindestens einen Wasserstoffbindungsdonator umfasst.
- 23.** Vorrichtung nach Anspruch 22, wobei das mindestens eine quaternäre Ammoniumsalz ausgewählt ist aus Cholinchlorid, Tetramethylammoniumchlorid (TMACl), Tetrapropylammoniumbromid (TPMBr), N-Ethyl-2-hydroxy-N,N-dimethylethanaminiumchlorid, 2-(Chlorcarbonyloxy)-N,N,N-trimethylethanaminiumchlorid, N-Benzyl-2-hydroxy-N,N-dimethylethanaminiumchlorid, Tetrabutylammoniumchlorid, Tetrabutylammoniumtrifluormethansulfonat und jede Mischung davon.
- 24.** Vorrichtung nach Anspruch 22 oder 23, wobei der mindestens eine Wasserstoffbrückenbindungsdonor ausgewählt ist aus Harnstoff, Polyethylenglykol, Glycerin, Polypropylenglykol, Acetamid, 1-Methylharnstoff, 1,3-Dimethylharnstoff, 1,1-Dimethylharnstoff, Thioharnstoff, Benzamid, Oxalsäure, Glycerin, Benzoesäure, Malonsäure, Adipinsäure, Zitronensäure, Bernsteinsäure, Succinonitril und jeder Mischung davon.
- 25.** Vorrichtung nach einem der Ansprüche 1 bis 24, wobei die elektrisch aufladbaren Platten jeweils aus mindestens einem leitfähigen Material bestehen, das aus Aluminium und Aluminiumlegierungen, Magnesium und Magnesiumlegierungen, Zink und Zinklegierungen, rostfreiem Stahl, Nickel und Nickellegierungen, Silber und

Silberlegierungen, Gold und Goldlegierungen, Kupfer und Kupferlegierungen, Graphit und dotiertem Graphit, Graphen und dotiertem Graphen, Kohlenstofffaser und Kohlenstofffaserverbundstoff ausgewählt ist.

26. Vorrichtung nach Anspruch 25, wobei die elektrisch aufladbaren Platten aus Kohlefaser oder Kohlefaserverbundwerkstoff hergestellt sind.

27. Vorrichtung nach Anspruch 25 oder 26, wobei die elektrisch geladenen Platten zum Schutz vor Korrosion behandelt sind.

28. Die Vorrichtung nach einem der Ansprüche 1 bis 27, wobei jede der elektrisch aufladbaren Platten eine bipolare Platte ist.

29. Die Vorrichtung nach einem der Ansprüche 1 bis 28, wobei die Vorrichtung eine Vielzahl der elektrochemischen Einheiten umfasst.

30. Vorrichtung nach Anspruch 29, wobei die elektrisch aufladbaren Platten eine Vielzahl von ersten elektrisch aufladbaren Platten und eine Vielzahl von zweiten elektrisch aufladbaren Platten umfassen, die abwechselnd in der Vorrichtung angeordnet sind, wobei die ersten Platten und die zweiten Platten mit entgegengesetzten elektrischen Ladungen aufladbar sind.

31. Vorrichtung nach Anspruch 30, wobei sich benachbarte elektrochemische Einheiten eine gemeinsame elektrisch aufladbare Platte teilen.

32. Vorrichtung nach Anspruch 31, wobei die elektrisch aufladbaren Platten bipolare Platten sind und jede elektrochemische Einheit zwischen einer ersten aufladbaren Fläche einer bipolaren Platte und einer zweiten aufladbaren Fläche einer benachbarten bipolaren Platte definiert ist, wobei die ersten und zweiten aufladbaren Flächen entgegengesetzt aufladbar sind.

33. Energiespeichervorrichtung mit mindestens einer elektrochemischen Einheit, die in eine gesättigte elektrolytische Lösung eines oder mehrerer wasserlöslicher Metallhalogenidsalze eingetaucht ist, wobei die Energiespeichervorrichtung im Wesentlichen gasdicht ist und die elektrochemische Einheit Folgendes umfasst

mindestens zwei elektrisch aufladbare Platten, von denen jede in Kontakt mit einem Stromabnehmerelement steht,

eine poröse, nicht leitende Membran, die zwischen den mindestens zwei elektrisch aufladbaren Platten angeordnet ist, und

ein leitendes Medium, das sandwichartig zwischen den mindestens zwei elektrisch aufladbaren Platten angeordnet ist, wobei das leitende Medium eine faserige leitende Matrix umfasst, die mit mindestens einem superabsorbierenden leitenden Hydrogel und mindestens einem anorganischen wasserstoffabsorbierenden Additiv auf Kohlenstoffbasis beladen ist.

34. Energiespeichervorrichtung mit mindestens einer elektrochemischen Einheit, die in eine gesättigte elektrolytische Lösung eines oder mehrerer wasserlöslicher Metallchloridsalze eingetaucht ist, wobei die Energiespeichervorrichtung im Wesentlichen gasdicht ist und die elektrochemische Einheit umfasst

mindestens zwei elektrisch aufladbare Platten, von denen jede in Kontakt mit einem Stromabnehmerelement steht,

eine poröse, nicht leitende Membran, die zwischen den mindestens zwei elektrisch aufladbaren Platten angeordnet ist, und

ein leitfähiges Medium, das sandwichartig zwischen den mindestens zwei elektrisch aufladbaren Platten angeordnet ist, wobei das leitfähige Medium eine faserige leitfähige Matrix umfasst, die aus Kohlenstofffilz, Graphitfilz und Polyacrylnitrilgraphitfilz ausgewählt ist, wobei die faserige leitfähige Matrix mit (i) mindestens einem superabsorbierenden leitfähigen Hydrogel, das eine Mischung aus Natriumpolyacrylat und Kaliumpolyacrylat umfasst, und (ii) mindestens einem anorganischen wasserstoffabsorbierenden Additiv auf Kohlenstoffbasis, ausgewählt aus graphitischem Kohlenstoffnitrid, Blähgraphit und expandiertem Blähgraphit, beladen ist.

35. Eine Energiespeicheranordnung, die zwei oder mehr Vorrichtungen nach einem der Ansprüche 1 bis 34 umfasst.

36. Verfahren zum Speichern von Energie in einer Vorrichtung nach einem der Ansprüche 1 bis 34, umfassend:

entgegengesetztes elektrisches Aufladen der mindestens zwei elektrisch aufladbaren Platten, um Energie in die Vorrichtung einzuführen und das eine oder die mehreren Metallsalze und Wasser in der gesättigten Elektrolytlösung zu elektrolysieren, um elektrische Ladungsträger zu erhalten, und

die es den elektrischen Ladungsträgern ermöglicht, sich während der elektrischen Aufladung zu elektrisch neutralen Gasmolekülen zu verbinden, die in dem

leitenden Medium eingeschlossen sind, wodurch die Energie in der Vorrichtung gespeichert wird, wobei die Vorrichtung im Wesentlichen gasdicht ist, um die Gasmoleküle in der Vorrichtung zu halten.

37. Verfahren nach Anspruch 36, wobei die Gasmoleküle in dem leitfähigen Hydrogel eingeschlossen und an das mindestens eine gas-physisorbierende Material physisorbiert werden.

38. Verfahren zur Gewinnung von Energie aus der Speichereinrichtung nach einem der Ansprüche 1 bis 34, umfassend:

Laden der Vorrichtung gemäß dem Verfahren nach Anspruch 36 oder 37; und
Umkehrung der Polarität in den mindestens zwei entgegengesetzt geladenen elektrisch aufladbaren Platten, um die Desorption der Gasmoleküle aus dem leitenden Medium zu ermöglichen, und

die es den Gasmolekülen ermöglichen, miteinander zu reagieren, wodurch Energie in Form von Elektronen freigesetzt wird,

Die Elektronen werden von der Lösung über ein leitfähiges Medium zu den Stromabnehmern übertragen.

39. Verfahren nach einem der Ansprüche 36 bis 38, wobei das eine oder die mehreren Salze ausgewählt sind aus Natriumchlorid, Kaliumchlorid, Aluminiumchlorid, Calciumchlorid, Magnesiumchlorid, Titanchlorid, Lithiumchlorid, Zinkchlorid, Nickel(II)-chlorid, Eisen(II)-chlorid, Eisen(III)-chlorid und jeder Mischung und/oder jedem Hydrat davon.

40. Verfahren nach Anspruch 39, wobei die Gasmoleküle Wasserstoff (H_2) und Chlor (Cl_2) sind.

41. Vorrichtung zur Verwendung bei der Erzeugung von Energie aus Wasserstoffgas und Chlorgas, wobei die Vorrichtung mindestens eine elektrochemische Einheit umfasst, die in eine elektrolytische Lösung eingetaucht ist, und die elektrochemische Einheit umfasst:

einen ersten Einlass zur Einleitung von Wasserstoffgas in die Vorrichtung und
einen zweiten Einlass zur Einleitung von Chlorgas in die Vorrichtung,

mindestens zwei elektrisch aufladbare Platten, von denen jede in Kontakt mit einem Stromabnehmerelement steht,

eine Polymerelektrolytmembran, die zwischen den mindestens zwei elektrisch aufladbaren Platten angeordnet ist, und

ein leitfähiges Medium, das sandwichartig zwischen den mindestens zwei elektrisch aufladbaren Platten angeordnet ist, wobei das leitfähige Medium eine poröse leitfähige Matrix umfasst, die mit mindestens einer leitfähigen Hydrogelzusammensetzung und mindestens einem gasphysikalisch absorbierenden Material beladen ist, das so konfiguriert ist, dass es mindestens eines der Gase Wasserstoff und Chlor absorbiert,

die elektrolytische Lösung ist eine gesättigte elektrolytische Lösung eines oder mehrerer Metallhalogenidsalze,

die Vorrichtung ist so abgedichtet, dass gasförmige Stoffe nicht aus der Vorrichtung austreten können.

42. Vorrichtung zur Verwendung bei der Erzeugung von Energie aus Gasmolekülen, wobei die Vorrichtung mindestens eine elektrochemische Einheit umfasst, die in eine elektrolytische Lösung eingetaucht ist, und die elektrochemische Einheit umfasst:

einen ersten Einlass zum Einleiten eines ersten Gases in die Vorrichtung und einen zweiten Einlass zum Einleiten eines zweiten Gases in die Vorrichtung,

mindestens zwei elektrisch aufladbare Platten, von denen jede in Kontakt mit einem Stromabnehmerelement steht,

eine Polymerelektrolytmembran, die zwischen den mindestens zwei elektrisch aufladbaren Platten angeordnet ist, und

ein leitfähiges Medium, das sandwichartig zwischen den mindestens zwei elektrisch aufladbaren Platten angeordnet ist, wobei das leitfähige Medium eine poröse leitfähige Matrix umfasst, die mit mindestens einer leitfähigen Hydrogelzusammensetzung und mindestens einem gas-physisorbierenden Material beladen ist, das so konfiguriert ist, dass es mindestens eines der ersten und zweiten Gase absorbiert,

die elektrolytische Lösung ist eine gesättigte elektrolytische Lösung eines oder mehrerer Metallsalze,

die Vorrichtung ist so abgedichtet, dass gasförmige Stoffe nicht aus der Vorrichtung austreten können.

