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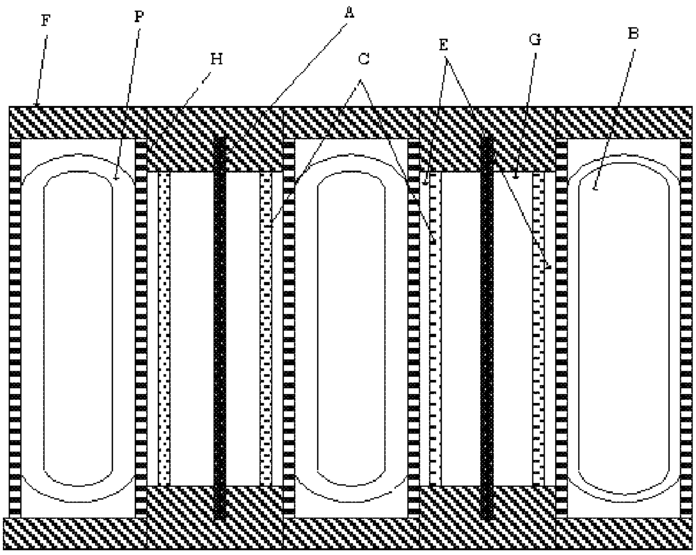
(54) Title: LOW-ENERGY-NUCLEAR-REACTION BASED ENERGY SOURCE

FIGURE 3



(57) Abstract: A nuclear energy source comprises a chamber containing an anode and a cathode having on its surface an active layer of palladium grains, an electric supply, a thermoelectric converter, and a heat collection system. The chamber may have a planar, cylindrical, or dual-cell configuration and may additionally comprise insulation to minimize parasitic heat loss. The nuclear energy source is used to produce thermal, electrical, or mechanical energy. Multiple dual-cell chambers may be arranged in two- or three- dimensional compact arrays to provide energy for a heat engine, such as a gas turbine, steam engine, or thermoelectric converter. Methods of generating nuclear energy by cold fusion and producing grains for a cold-fusion cathode are disclosed.

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TITLE OF INVENTION

Low-Energy-Nuclear-Reaction Based Energy Source

TECHNICAL FIELD

The present invention relates to means for producing useful energy from the nuclear energy released in Low Energy Nuclear Reactions, commonly called LENR or Cold Fusion.

BACKGROUND ART

In 1989 Pons and Fleischman reported the first successful Low Energy Nuclear Reaction ("LENR") of the electrolysis type in "Journal of Electroanalytical Chemistry", Volume 261, Issue 2, Part 1, 10 April 1989, pages 301-308. The announcement of the discovery by Pons and Fleischman was received with much interest and excitement that soon dissipated, as few people were able to duplicate the results. At that time there was no known physical explanation for how the reactions could occur at room temperature. Since then, many groups at institutions in many countries, including the United States, have duplicated the experimental effects in a variety of experiments.

A new theory proposed by Russell, one of the present Applicants, explains the nuclear and atomic reactions that result in controlled release of nuclear energy as heat in LENR energy generation. The theory is given in the paper "Low-Energy-Nuclear-Reaction Polyplasmon Postulate". The paper, after peer review, was published in "Annals of Nuclear Energy" Volume 35, Issue 11, November 2008, pages 2059-2072. It describes and mathematically models a sequence of events that are consistent with certain conditions that are present in successful LENR experiments of the electrolysis type first reported by Pons and Fleischman.

The referred paper proposes a theory that explains the reported repeatable observed results of LENR experiments of Pons and Fleischman, electrolysis type experiments and also experiments that use deuterium plasma, instead of an electrolyte, to conduct positive ions to an appropriate cathode. The proposed theory is called a postulate until certain experimental results are independently duplicated. However, the postulate is founded on accepted quantum mechanical principles. Based on the understanding that the proposed theory provided, the present inventors approached the problem of implementing practical applications for this new energy source with some insight rather than simply "trial and error."

SUMMARY OF THE INVENTION

In accordance with the present invention, three critical conditions must be met to initiate LENR activity in electrolysis or plasma type experiments. First, an electrically conducting surface, the cathode, must have crystalline metallic grains of palladium, certain other palladium alloys, or possibly other metals, on its surface of dimension between a fraction of one micron to perhaps two hundred microns. Second, the grains must be capable of containing a concentration of the hydrogen isotope, deuterium, greater than about 70%. And third, the grains must be bombarded by deuterium ions (i.e. deuterons) in order to create polyplasmons in the grains. Bombarding with ions of other than deuterium would introduce impurities and degrade the ability to sustain plasmon waves in the grains. In addition, bombarding with deuterons helps to create and maintain a high concentration of deuterons in the grains.

To be most efficient, the entire active cathode surface should be covered with the potentially active crystalline grains, because coherent plasmon fields can only exist in the electronic resonance structure of the individual crystalline metal grains. It is the energy of the coherent plasmon field (the polyplasmon) that enables the LENR reactions. While it is possible for grains below the surface layer of grains to become activated by conduction processes, it is a relatively inefficient process, so that nearly all of the nuclear activity takes place in the surface grains.

The properties of palladium metal are well suited to this application. Most successful LENR experiments have used it. However, some successful experiments have been reported using other metals or alloys. The typical successful experimental electrolysis cell, see FIG. 1, is placed in a calorimeter and activated by the current from the external power supply. A successful experiment is indicated if the calorimeter measures more heat energy output than the electrical energy input from the power supply.

Assuming the three conditions are met, the sequence of events that lead to nuclear reactions in a typical successful electrolysis-type experiment are as follows:

(1) The concentration of deuterium atoms in the cathode metal grains is increased so that there is at least about 0.7 deuterium atoms per palladium atom.

(2) The deuterons, flowing into the surface of the palladium cathode, interact with electrons in the metallic cathode and release the resultant energy in some of the grains at or near the cathode surface. This energy is in the form of plasmons that are pressure waves in the conduction electrons in the grain. The interior reflecting surfaces of the grain boundaries make the grain a resonant cavity for the plasmon waves. Like sound in an organ pipe, continued excitation increases the intensity of the confined wave of coherent plasmons called a polyplasmon.

(3) The polyplasmon field can have sufficient energy to allow the nucleus of one of the deuterium atoms in the grain to capture its own electron by absorbing energy from the polyplasmon field. The quantum mechanical calculation of the rate of this reaction is in the referred paper.

(4) The deuteron, having captured its own orbiting electron, has become a dineutron by the endothermic reaction that converts the proton in the deuteron into a neutron with an associated neutrino. This requires 783 keV of energy that is supplied by the polyplasmon field.

(5) The new neutron has a short lifetime because it has an associated neutrino that either must react with the neutron to return it to being a proton plus an electron, or be abandoned as a result of a nuclear reaction that frees the neutrino to become an orphan that leaves the system. However, the dineutron has a very high probability of being captured in a nearby nucleus.

(6) When the dineutron is captured by a nearby deuteron, the resulting reaction creates a helium nucleus plus a low energy electron in a helium atomic bound state. The 24.629 MeV of released nuclear energy manifests as a large increase in the strength of the polyplasmon field of the grain. This causes another reaction and the cycle repeats resulting in a chain reaction in the grain.

(7) The chain reaction continues at an extremely rapid rate until the process is stopped either because of random losses of energy from the grain, or because the grain temperature has increased to the point that its electrical and mechanical properties have changed so that it no longer can support a resonant polyplasmon field.

(8) After cooling, the grain, if not too damaged, may recover and repeat the cycle, until the grain is so modified that it cannot support a polyplasmon field of intensity sufficient to initiate nuclear reactions.

The probability is small that a piece of palladium metal, acquired commercially, will have grains covering a significant fraction of its surface, that are pure enough, have adequately reflective internal surface properties and are within a useful size range for LENR. This is perhaps the main reason why most palladium cathodes do not exhibit LENR phenomena. Even those that produce positive results may have very few active grains. The reason these few active grains can result in observable effects is because of the chain reaction effect. If it were not for the chain reaction effect, it is unlikely that excess energy would ever have been noticed.

Although the above scenario refers to the electrolysis class of LENR experiments, the arguments and conclusions are the same for the ionized-gas class of experiments of the present invention. The ionized-gas-type experiments differ from the electrolysis-type experiments in that, instead of a water solution between the cathode and anode, ionized deuterium gas plasma fills that space. The current of deuterons arriving at the cathode surface equals the corresponding current of electrons flowing into the anode, as in the liquid water experiments. The plasma experiments are of particular interest because they demonstrate that it is not necessary for a high temperature cell to contain water at high pressure and temperature. More importantly, only deuterium gas is present in a gas-type system. In heavy water systems both deuterium and oxygen gases are produced. Explosions of such laboratory water experiments are not uncommon. An acceptable water-based system for large scale commercial distribution to the public may not be economically achievable. A deuterium gas cell, by having no means for creating oxygen in the cell, avoids the problem inherent in water-based systems of accidental catalyst failure to keep mixed deuterium and oxygen gases below detonation density.

The efficiency of conversion of heat energy to mechanical or electrical energy is limited by the theoretical Carnot Efficiency (CE).

CE = (input temperature — heat rejection temperature) / (input temperature)

Temperature units are in degrees Kelvin. This equation means that higher efficiency generation of electrical energy can be achieved either by a source of higher temperature heat, or a lower heat rejection temperature, or both.

A limitation on the efficiency of a LENR energy source is that the equilibrium deuterium concentration in the cathode is inversely related to the temperature of the palladium cathode. Higher cathode temperatures correspond to lower equilibrium deuterium concentration in the cathode. Increasing deuterium gas pressure in the cell increases the equilibrium concentration of deuterium in the palladium cathode, but above a critical pressure, a stable plasma cannot be practically initiated or sustained. Optimum operating parameters and design properties of the source are determined by the requirements of the intended application.

Industrial Applicability

This patent discloses a nuclear energy source used to supply high temperature heat, or to produce thermal, electrical, or mechanical energy. The patent describes methods for generating nuclear energy and methods for preparing cathodes for use in the invention, with active surfaces that are made up of separate, closely-spaced, crystalline grains. The patent also discloses methods of producing the metallic grains.

One embodiment of the invention is a nuclear energy source that is used to produce thermal, electrical, or mechanical energy. In accordance with this embodiment, the source comprises a chamber comprising at least one cathode, at least one anode, an electric supply, and deuterium gas. The cathode comprises an inert metal surface that is coated with an active metallic layer of palladium, another metal, or a metal alloy which has a thickness between about 0.1 and 200 microns and is divided into arrays of single metallic crystalline grains. The metallic layer, preferably palladium, can contain a significant concentration of hydrogen or deuterium. The electric supply provides a time-dependent electric potential applied between the cathode and anode, preferably controlled by an electronic control system. The time-dependent electric potential comprises repetitive higher-voltage pulses. Depending on the application requirements, these higher-voltage pulses may be superimposed upon a lower steady-state voltage.

In an embodiment of the invention, the chamber has a generally planar configuration wherein the anode is substantially parallel to the cathode. In an alternative embodiment, the chamber has a cylindrical geometric configuration wherein the anode and cathode are comprised of concentric metal cylinders.

The nuclear energy source may further comprise a thermoelectric converter and a heat-collection system, wherein the thermoelectric converter is in thermal contact with both the cathode and the heat-collection system. A typical heat-collection system for terrestrial applications comprises a heat-transfer fluid pipe, (P) as shown in FIG. 2, FIG. 3, and FIG. 4, for example a radiator fluid duct, an air cooling duct, or a cooling fin in ambient air or water, or a combination thereof. A typical heat- collection system for use in extraterrestrial applications comprises a means of radiation to cold space.

In an alternative embodiment of the invention, the chambers having a cylindrical configuration have attached a heat-collection system which comprises a cylindrical pipe having an external surface on which the cathode is located.

Another embodiment of the invention includes a nuclear energy source which has a dual-cell-configuration chamber wherein the anode is symmetrically located between two cathodes, enabling heat collection from both sides of the chamber. The dual-cell chamber may further comprise a thermoelectric converter and a heat-collection system wherein the thermoelectric converter is in thermal contact with both the cathodes and the heat-collection system.

In another embodiment, a nuclear energy source of the present invention comprises a multiplicity of dual-cell chambers and heat-collection ducts arranged in a compact array. The arrays may be two-dimensional or three-dimensional, wherein the two faces of the cells are in thermal contact with the heat-collection ducts that have two parallel faces. For illustrative examples, see FIG. 2 and FIG. 3. Such dual-cell chambers transfer heat to a fluid or gas that is used to provide energy to a heat engine, such as a gas turbine, steam engine, or thermoelectric converter. Preferably, the arrays are arranged in a compact configuration. Most preferably the chambers further comprise insulation that surrounds the chamber to minimize parasitic heat loss from the anode. The nuclear energy from the dual-cell chambers can be used to boil water, produce steam or vapor, feed a turbine or a steam engine, provide heat for manufacturing chemicals, or provide mechanical power.

Another aspect of the present invention is a method for generating nuclear energy that is used to produce thermal, electrical, or mechanical energy. The method comprises supplying a time-dependent electric potential, in the presence of deuterium gas, between at least one cathode having an inert metal surface coated with palladium grains, and at least one anode having a metallic surface, wherein said time-dependent electric potential comprises a repetitive higher-voltage pulse with a duration of from 0.1 to 40 microseconds superimposed upon a lower steady-state voltage wherein said steady-state voltage is high enough to draw deuterium ions through the gas towards the cathode without producing ionization that would support sparking. The high temperature heat is collected via a heat-collection system and the heat can be used directly or can be used to generate electricity. The heat can be converted via a thermoelectric converter into usable thermal, electric, or mechanical energy.

In preferred embodiments the duration of each of the higher-voltage pulses is about 1 to 10 microseconds. In some of the most preferred embodiments, the duration of each of the higher-voltage pulses is about 1.5 microseconds.

Another aspect of the present invention is a method for producing grains for a cold fusion cathode which comprises polishing a support plate of a non-reacting metal to a mirror finish, depositing a thin, uniform film of a surface metal having a thickness of about 0.1 to about 200 microns, cutting, for example by laser ablation, the surface layer into single crystalline grains of dimensions of about 0.5 to 200 microns separated from each other by the width of the cut, whereby the grains retain a relatively high concentration of dissolved deuterium. The surface metal may be deposited by electroplating, vapor deposition (sputtering), chemical vapor deposition, or any other method that results in a film of uniform thickness. Palladium is a preferred surface metal. The grains are cut into any geometrical shape that can contain resonant standing waves in the conduction electrons. For example the cuts can be in the shape of circles, ovals, triangles, squares, rectangles, tetragons, quadrilaterals, pentagons, hexagons, and any other shape that can support standing waves in the crystalline grains. Preferred shapes are squares and rectangles.

As a further embodiment of the invention, the above method for producing grains may comprise the further step of introducing onto the support plate from 1 to 100 atomic monolayers of a different chemical element, such as manganese, to insure that the boundary at the interface between the support plate and the metal grains has high internal reflectivity for the plasmons, but retains sufficient electric conductivity to complete the current path in the cell from the external electrical supply.

An alternative embodiment for producing grains for a cold-fusion cathode comprises the method steps of polishing a support plate of a non-reacting metal to a mirror finish, using photoresist technology to mask the space on the support plate required for separating the grains, depositing a thin film of a surface metal having a substantially uniform thickness of about 0.1 to about 200 microns onto the support plate. The masking is then removed, leaving an intact array of grains on the previously-unmasked portions of the support plate's metal surface.

An embodiment of the invention is a cathode with an active surface comprising a plurality of separate, closely spaced grains produced by either the depositing/cutting process or the photoresist process described above.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG.l is a diagrammatic representation of a single dual-cell chamber which contains an anode (A) and two cathodes (C).

FIG. 2 shows a gas design with a dual cell from which high temperature heat can be extracted by circulating loops. It contains an anode (A); a heat-transfer fluid pipe (P); a cathode (C); a heat transfer fluid (B); external cell walls (E); an insulator (F); and a plasma region (G).

FIG. 3 shows a gas design with a dual cell wherein the produced heat is conducted through a thermoelectric converter. It contains a metallic anode (A); a heat-transfer fluid pipe (P); a cathode (C); a heat transfer fluid B); external cell walls (E); an insulator (F); a plasma region (G); and a thermoelectric converter (H).

FIG. 4 shows a gas design with a cylindrical system having a concentric tube design. It contains a metallic anode (A); heat transfer fluid (B); a cathode (C); a heat-transfer fluid pipe (P); and a plasma region (G).

FIG. 5 is a qualitative graph of cathode temperature vs. time for initial startup. T(max) is the grain temperature that terminates the chain reaction.

FIG. 6 is a qualitative graph of cathode temperature vs. time for start up and for steady state conditions as controlled by pulsing the cathode voltage. T(max) is the grain temperature that terminates the chain reaction; T(avg) is the average grain temperature of a grain averaged over one pulse cycle; and T(min) is the grain temperature just before it is pulsed to start the next chain reaction.

FIG. 7 shows a "classical" (Prior Art) electrolysis cell design with a metallic anode (A) such as a screen or plate of an inert metal such as platinum; a DC electric current supply (B); a metal cathode of palladium, another metal, or an alloy that can contain sufficient dissolved deuterium (C); and a heavy water electrolyte (J) made conducting by addition of a soluble salt.

DEFINITIONS

"Deuterium" refers to the hydrogen isotope of mass 2 frequently called "heavy hydrogen". In the context of this invention, deuterium gas may comprise pure deuterium or mixtures of deuterium and hydrogen wherein the deuterium component of the mixture is at least about 98%.

"Fluid" is a substance that continually deforms (flows) under an applied shear stress. Fluids are a subset of the phases of matter and include liquids, gases, plasmas, and, to some extent, plastic solids.

"Grain," "metallic grain," and "crystalline grain" are terms that refer to small metal structures that often randomly form in many kinds of molten metals when they are allowed to cool and solidify. They are characterized by a regular ordering of the metal atoms in a repeating pattern throughout a small volume of the metal, called a grain. Carbon atoms can be arranged in a regular lattice configuration to form the substance of a diamond, in which the material properties of the diamond are exactly the same throughout the volume of the gem. In the same way, the properties of a metal grain are the same throughout the grain. The significance of this to LENR is that plasma waves in the conduction electrons of the metal grain have very few irregularities to scatter from because of the regularity of the lattice, and therefore can have very few means for losing energy and being dissipated. An analogy would be an organ pipe which can support a resonant sound wave when air is moving past its orifice. As metallic grains form, by solidifying as the temperature of the metal cools, the metal impurities tend to be pushed to the surface of the grain, resulting in a uniform lattice of palladium atoms. However, because the freezing formation of grains is a random process, only a very small fraction of the grains formed during the solidification of a molten metal will have all the properties required to be capable of supporting a polyplasmon field.

By "higher-voltage pulse" we mean an electrical pulse of short duration that is higher than the bias or base voltage applied between the cathode and anode surface and transfers enough energy to enable the nuclear reactions to occur. Typically the higher-voltage pulse may be up to about 100 volts. The amount of energy input to the deuterium by the pulse is in excess of 783 keV, which is the minimum amount required to create plasmons with sufficient energy to initiate relevant nuclear reactions.

An illustrative example of a typical circuit would allow for the generation of a train of higher-voltage pulses separated by intervals of low applied voltage. Such a circuit allows one to adjust the pulse parameters that drive the nuclear reaction. An illustrative example of the control system would comprise a bias-voltage DC power supply of 0 to 20 volts, an external variable-DC power supply providing a voltage input of 0 to 100 volts, and a transistor supplying a pulsing signal. The timing provided by such a circuit may be about 100 pulses per second at maximum power.

A "plasmon" is a pressure wave in the conduction electrons (the ones that are free to move around) in a metal. Like a sound wave in an organ pipe, if it is created in a space with reflecting walls, it will have a frequency, or harmonic, corresponding to the size of the volume. Many plasmons in the same grain, that are created in phase and have the same frequency and spatial distribution, are called a "polyplasmon" and said to be "coherent".

DETAILED DESCRIPTION OF THE INVENTION

While the general types of LENR energy sources described in this invention, FIG. 2, FIG. 3, and FIG. 4, are different from the "classical" electrolysis type of source, they meet the three necessary conditions described above. They use a cathode (C) comprised of palladium crystalline grains formed on, or attached to, a conducting metal support plate. The grains on the cathode surface can each support a polyplasmon field. The voltage difference between the cathode and anode, and therefore deuteron current into the cathode, are time dependent. In order to help maintain a high concentration of deuterium in the grains, a constant lower voltage between pulses maintains the plasma at a deuteron current level below that required to produce polyplasmons with enough energy to create dineutrons. Periodically superimposed on the constant voltage is a voltage pulse of the order of a few microseconds duration that temporarily increases the current of deuterons bombarding the cathode to above the threshold rate for creating polyplasmons of sufficient energy to permit formation of dineutrons. This initiates the LENR chain reactions.

A second function of the constant low-level current is that it provides a relatively uniform conductive volume between the cathode and anode so that the higher-voltage pulses result in a relatively uniform flow of deuterons to the cathode surface. Without the continuous plasma, the current during the high voltage pulse to the anode may not be uniformly distributed over the cathode surface, and also may have a tendency, under some circumstances, to result in a spark discharge.

As shown in FIG. 2 and FIG. 3, the cathodes (C) and anodes (A) are mechanically supported by ceramic insulators (F). These insulators also provide the vacuum tight seal around the cell edges in order to contain the deuterium gas. Electrical connections to the anode and cathode are made by wires that pass through, and are bonded to, the ceramic insulators. Similar functioning insulation and vacuum seals are required for the cylindrical cell of FIG. 4, though not indicated in the drawing. The specifics of the design of the thermal and electrical insulator design will depend strongly upon the specific application of the product.

Depending upon the application requirements, the deuterium gas in the cell either may be permanently sealed for the operational life of the cell, or the cell design can include a penetration for refreshing the gas during operation so as to extend the operating life of the system.

While plasmons are created by transfer of the energy released by the entry of deuterons, or protons, into the metal cathode in an electrolysis cell, each plasmon has only a few electron volts of energy and a lifetime of the order of a microsecond. Plasmons can be created in an amorphous metal cathode, but are incoherent, i.e., random in phase and direction. It follows that the about 9.7 eV energy of each plasmon is insufficient for supplying the 783 keV required to allow the deuteron to capture its electron. However, if the metal cathode, like many metals, contains crystalline metal grains ranging in size, depending upon metal manufacturing procedures, from a fraction of a micron to many microns in dimension, a different series of events becomes possible.

Plasmons created in the conduction electrons in a metal grain, like sound in an organ pipe, have a resonant frequency and phase determined by the size and shape of the grain and density of the conduction electrons in the metal. Continued excitation of the grain by the deuteron current increases the plasmon population only at the resonant frequency and in phase with the existing coherent plasmons, as a consequence of stimulated emission, resulting in a coherent standing wave of many plasmons called a polyplasmon. This reservoir of energy, the polyplasmon, is the key to understanding the LENR process, because it can provide the energy required to create the dion and the dineutron, as well as be a temporary reservoir for the nuclear energy released in the most significant energy producing reactions.

Nuclear energy released by dion capture in the metal hydride is very large and depending upon the particular reaction, either deposits the energy in the grain as polyplasmon energy, or it produces localized, highly ionized tracks in the grains. Much of the ionization energy couples to the polyplasmon field. In the case of (Dn, d) helium production, nearly all of the released nuclear energy is directly absorbed by the polyplasmon field. These reactions can lead to a cycle in which the intensity of the depleted plasmon field is re-energized with each succeeding reaction. These stochastic processes continue until either the chain is broken by random loss of the constituents, or until the grain temperature increases enough to alter its properties so that the plasmon field is destroyed. After cooling, the process may repeat, provided the crystal structure of the grain has not been so altered that it cannot recover simply by cooling.

A more complete description of these processes is given in the paper by Applicant John L. Russell, Jr., "Low-Energy-Nuclear-Reaction Polyplasmon Postulate" published in "Annals of Nuclear Energy" Volume 35, Issue 11, November 2008, pages 2059-2072.

Among the advantages of these LENR systems for generating heat above 100 degrees Centigrade, in addition to avoiding the potential for deuterium-oxygen explosions, is that they operate at lower pressures than water electrolyte based systems with the same output temperature. However, the higher temperature plasma systems are limited by the amount of deuterium contained in the palladium cathode because higher temperature palladium crystals hold less deuterium. This is partially compensated by the constant deuteron bombardment of the cathode with low energy deuterons between the higher voltage pulses that initiate the chain reactions. Actual operating temperatures depend upon application requirements, specific system design details and operating conditions.

While the technology described in this patent only refers to palladium metal for the deuterium- containing cathode, there are alloys of palladium that can serve the function of the deuterium- containing cathode. At this time, it appears that palladium metal is the most promising material for the cathode surface grains. However, there are other metals and alloys (for example nickel and some of its alloys) that can absorb deuterium gas and, in principle, can exhibit some of the LENR effects.

Because essentially all of the nuclear reactions occur in grains on the surface of the cathode, high efficiency requires a high fraction of cathode surface to be covered by grains capable of supporting a plasmon field. This capability can be achieved by fabricating a single layer of palladium grains on a support plate of a non-reacting metal such as stainless steel. For example, this can be done by first polishing the support plate metal surface to a mirror finish and then depositing on the surface a thin film of palladium of substantially uniform thickness in the range of about 0.1 microns to about 200 microns. The thickness selected depends upon system requirements. The deposition can be done by electroplating, vapor deposition (sputtering), chemical vapor deposition, or any other method that results in a film of substantially uniform thickness with very few cracks or other inhomogeneous features in the deposited palladium.

This surface layer can then be cut into appropriately sized single crystals, separated from each other by the width of the cut. Suitable techniques for cutting the grains include laser cutting, ablation, or electrical spark erosion cutting. Any other method that results in well-defined surface crystalline grains of palladium is also suitable. The simplest and perhaps the most efficient shapes for the grains are formed by cutting the uniform layer of deposited palladium into squares or rectangles to form cubes, prisms, or any other shapes that can support a standing wave, also known as a coherent polyplasmon.

Although fundamentally more complex, another method for forming grains on the surface of the support plate involves use of masking techniques, such as covering the space required for separating the grains, utilizing photoresist technology commonly used for manufacturing electronic circuits, for example, so that palladium only remains deposited in the unmasked areas. One method of applying this technique includes the method steps of polishing a support plate of a non-reacting metal to a mirror finish, using photoresist technology to mask the space on the support plate required for separating the grains, and depositing a thin film of a surface metal, such as palladium, onto the support plate. The thin film of the surface metal should have a substantially uniform thickness in the range of about 0.1 to about 200 microns (i.e. micrometers). The masking is then removed leaving an intact array of grains that is deposited on the unmasked portions of the support plate's metal surfaces.

Depending upon the choice of substrate metal, it may be necessary to introduce a few, typically 1 to 100, monolayers of a different chemical element, such as manganese, between the grain and the supporting substrate to insure a boundary at that interface that has high internal reflectivity for the plasmons. The other surfaces of the crystalline grains are bare and exposed only to the deuterium gas in the cell and therefore have very high internal reflectivity for the polyplasmon.

FIG. 2 illustrates a dual cell from which high temperature heat can be extracted by circulating loops of the heat transfer pipe (P). For example, the heat can be used with a direct conversion device that is located separately from the cell, or as the heat source for a turbine or steam engine to produce mechanical energy or electrical energy, or perhaps as a heat source for industrial or domestic use, or as the heat source for any other applications where the unique characteristics of the LENR source are advantageous.

FIG. 3 illustrates a plurality of dual-cell chambers in which solid-state direct Thermo-Electric Conversion ("TEC") devices (T) are placed between the hot cathodes of the cell structure and the coolant fluid channels. The high temperature heat is produced in the cathodes (C) that are in thermal contact with the TEC devices. The anode (A), serving both sides of the cell, operates at essentially the same temperature as the two cathodes. The principal parasitic high-temperature heat leakage is through the metallic electrical connections and the ceramic insulators (I) around the four edges of the dual-cell chamber. Low-temperature heat rejection is through the coolant fluid channels in thermal contact with outer surfaces of the TECs on both faces of the dual cell chamber. This design allows stacking cells both horizontally and vertically, creating a compact three-dimensional array of dual-cell chambers. Coolant fluid is distributed and collected by header systems on the two faces of the array, perpendicular to the pipes carrying the reject heat from the TECs.

Thermoelectric converters are commercially available with efficiencies for heat-to-electricity of approximately half of the theoretical Carnot Efficiency Limit. Such products are available from Hi-Z Technology, Inc., 7606 Miramar Road, Ste 7400, San Diego, CA 92126. www.hi-z.com.

Because the polyplasmon is a standing wave, it has peaks and valleys in its spatial energy distribution. These peaks, or islands, occur on the grain surface and also in the interior at regularly spaced volumes at locations determined by the polyplasmon wavelength. It is generally the temperature at the hot islands that terminate the chain reaction, not the average temperature of the grain. The peak-to-average ratio of the spatial energy generation rate in an ideal rectangular crystal on the cathode is two.

The rate that an initial polyplasmon gains energy is determined by the product:

[(deuteron current per square cm) x (area of the grain's exposed surface) x (efficiency for converting the incident energy into plasmon energy)].

Because the polyplasmon is continually decaying at a rate proportional to its intensity, giving it a lifetime on the order of microseconds, the formation rate of the polyplasmon must be rapid enough to "grow" a useful field in microseconds. This phenomenon is responsible for the experimental observation that there is a threshold for the cathode current per square centimeter that must be exceeded to initiate LENR effects. However, once a chain reaction is initiated, the current is no longer needed to sustain the reaction in that grain. The chain reaction is self-terminating when the rising temperature causes a change in the grain properties that terminates the polyplasmon field. The ultimate temperature limit is the start of actual local melting of the crystal. Typically, other factors terminate the reaction before melting occurs.

Self-damping or termination of the chain reaction limits the design of any control system for a practical LENR energy source. On the positive side, this selflimiting characteristic of LENR reactions means that it is absolutely impossible to generate a "nuclear explosion," in the sense of an "atomic bomb". The simple reason is that melting even a small part of the metal grain destroys the polyplasmon field and therefore instantly terminates the possibility of further polyplasmon-induced nuclear reactions, until after the grain has cooled enough so that it may regain the ability to again support a polyplasmon field. These same phenomena mean that the heat rate cannot be continuously adjustable in the usual sense.

Control of the average heating rate of the cell is accomplished by adjusting the rate at which pulses of heat are generated. A heat pulse is initiated by raising the rate of deuteron bombardment of the cathode for a short period, typically a few microseconds, by momentarily raising the anode-to-cathode voltage to a value, above what is required to maintain the continuous low energy plasma in the space between the anode and cathode, to a voltage that produces an ion current sufficient to initiate a chain reaction.

FIG. 5 (start up) and FIG. 6 (steady state) are qualitative graphs illustrating the time dependence of a grain temperature. T(max) is the grain temperature that terminates the chain reaction, T(avg) is the average temperature of a grain averaged over one pulse cycle, and T(min) is the grain temperature just before it is pulsed to start the next chain reaction. The chain reaction is terminated by a local hot spot in a grain reaching a temperature T(max) that terminates the chain reaction. The temperature of the grain at that time ceases to increase and begins decreasing as the heat is conducted to the colder metal support plate. In the steady state, FIG. 6, the cycle repeats and maintains a constant average temperature. T(avg) approaches T(max) as the pulse rate increases, but never equals it. These properties are the basis for the ability to use pulse rate to control the average power of the cell. While this description is for an idealized system, the principles qualitatively apply to practical systems.

The metallic grains on the cathode surface must retain a relatively high concentration of dissolved deuterium in order to retain the ability to generate heat by LENR. Four factors influence this retention: cathode temperature, deuterium gas pressure, deuteron flux into the surface, and disturbance of the cathode grain lattice by internal nuclear reactions.

For applications requiring generation of electrical or mechanical energy, the efficiency for conversion of the heat is strongly dependent on the temperature of the heat source. However, the usual method of removal of dissolved gases from palladium is to raise the temperature of the metal to increase the rate of diffusion of gas from the metal. Raising the pressure of the deuterium, to reduce the temperature-induced diffusion from the cathode, to above about 0.5 atmosphere, makes it difficult to create stable plasma, because the gas breaks down above a critical voltage gradient and a damaging spark results. This is because the collision cross section of the electrons with the gas atoms decreases with increase of electron energy, allowing a longer path after each ionizing collision to increase its energy. A voltage gradient large enough to ionize the pressurized neutral gas can also be large enough to produce an electron cascade. In other words the electrons created at each collision with an atom, gain sufficient energy before the next collision to produce more cascading electrons. This cascade creates a low resistance path for a spark.

These considerations imply a practical upper limit to the average temperature at which the cathode can be operated. This limit will also depend upon several system parameters determined by the application requirements.

In the several classes of LENR devices discussed in this patent, other emission from (Pd + Dn) reactions. These reactions have a lower probability for significantly increasing the energy of the polyplasmons and hence a lower probability for continuing the chain reaction. Therefore some chain reactions are terminated early and this results in a statistical distribution of the temperature increases caused by the pulses of bombarding deuterons. The effect on the qualitative graphs in FIG. 5 and FIG. 6 is that the amplitudes of the temperature increases will have a statistical distribution not shown in the figures. This will not significantly change the effectiveness of the pulse rate control of the average heat output of the LENR device.

It is to be understood that the present invention may have various other embodiments. Furthermore, while the form of the invention herein shown and described constitutes a preferred embodiment of the invention, it is not intended to illustrate all possible forms thereof. It will also be understood that the words used are words of description rather than limitation, and that various changes may be made without departing from the spirit and scope of the invention disclosed. The scope of the invention should not be limited solely to the examples given.

CLAIMS

1. A nuclear energy source for producing thermal energy, comprising:
    a. a chamber comprising at least one cathode, at least one anode, and deuterium gas wherein said at least one cathode has an inert metal surface including an active metallic layer of uniform thickness between about 0.1 and 200 microns consisting of palladium, another metal, or a metal alloy, wherein said active metallic layer is adapted to contain a significant concentration of deuterium gas, and wherein said active metallic layer is an array of single, metallic, crystalline grains having dimensions between about 0.5 and 200 microns; and said at least one anode has an inert metallic surface; and
    b. an electric supply adapted to apply a time-dependent electric potential between the at least one cathode and the at least one anode, wherein said electric potential is a sequence of higher-voltage pulses with a duration of from 0.1 to 40 microseconds superimposed upon a lower steady-state voltage, wherein said steady-state voltage is high enough to draw deuterium ions through the gas towards the cathode without producing ionization that would support sparking; the electric supply further comprising an electronic control system for adjusting the pulse amplitude, rate, and/or duration of the higher-voltage pulse whereby to control the average temperature of the cathode, and therefore the average rate of energy production of the source.

2. The nuclear energy source of claim 1 wherein said chamber has a generally planar configuration and wherein each of the anodes has a metallic surface that is substantially parallel to a surface of the at least one cathode.

3. The nuclear energy source of claim 2 further comprising at least one thermoelectric converter having two sides, and at least one heat collection

system, wherein one side of each of the at least one thermoelectric converters is in thermal contact with at least one of the cathodes and the other side of each thermoelectric converter is in thermal contact with the heat collection system.

4. The nuclear energy source of claim 3 wherein said heat collection system comprises a heat-transfer fluid pipe or a cooling fin in ambient air or water, or a combination thereof.

5. The nuclear energy source of claim 3 wherein said heat collection system comprises a means of radiation to cold space, suitable for extraterrestrial application.

6. The nuclear energy source of claim 1 wherein said chamber has a cylindrical configuration and wherein the at least one anode and the at least one cathode comprise concentric metal cylinders.

7. The nuclear energy source of claim 6 further comprising at least one thermoelectric converter and at least one heat collection system, wherein one side of each thermoelectric converter is in thermal contact with at least one cathode and the other side of each thermoelectric converter is in thermal contact with a heat collection system.

8. The nuclear energy source of claim 7 wherein said heat collection system comprises a heat-transfer fluid pipe or a cooling fin in ambient air or water, or a combination thereof.

9. The nuclear energy source of claim 7 wherein the heat collection system comprises a means of radiation to cold space, suitable for extraterrestrial application.

10. The nuclear energy source of claim 7 wherein the heat collection system comprises a cylindrical pipe having an external surface in thermal-transfer proximity to a cathode, adapted for heat collection by flowing a fluid through the pipe.

11. A nuclear energy source of claim 1 wherein the nuclear energy source is configured as a dual-cell chamber and wherein the anode of the dual cell is located between two cathodes, enabling heat collection from both sides of the dual cell.

12. The nuclear energy source of claim 11 further comprising a thermoelectric converter and a heat collection system, wherein one side of the thermoelectric converter is in thermal contact with at least one cathode and the other side of the thermoelectric converter is in thermal contact with a heat collection system.

13. The nuclear energy source of claim 12 wherein said heat collection system comprises a heat-transfer fluid pipe or a cooling fin in ambient air or water, or a combination thereof.

14. The nuclear energy source of claim 13 wherein said heat collection system comprises a means of radiation to cold space, suitable for extraterrestrial application.

15. An array comprising a multiplicity of sources of nuclear energy as recited in claim 11, wherein the heat-collection system comprises a cooling duct containing a fluid, and wherein said multiplicity of sources of nuclear energy are stacked in a two- or three-dimensional array wherein the cathodes of each

cell, except the outermost ones, are in thermal contact with a heat collection duct that has a pair of parallel faces.

16. The array of claim 15 wherein the dual-cells that together constitute the array are disposed so as to transfer heat to the fluid in the heat-collection system.

17. The array of claim 16, further comprising a heat engine comprising a gas turbine, a steam engine, or a thermoelectric converter, that is supplied with heat energy by said fluid.

18. The array of claim 16, which further comprises insulation around said chambers to minimize parasitic heat loss from the cells.

19. The array of claim 15, which further comprises means to boil a liquid to produce vapor under pressure that is fed to a turbine to provide mechanical power.

20. The array of claim 19, wherein the liquid consists essentially of water.

21. An array comprising a multiplicity of said nuclear energy sources as recited in claim 6, wherein said array is arranged in a cylindrical configuration, wherein the heat collection system comprises a cooling duct, and wherein said multiplicity of sources are stacked in a two- or three-dimensional array.

22. The array of claim 21 which further comprises means to boil a liquid to produce vapor under pressure that is fed to a turbine to provide mechanical power.

23. A controlled method of producing useful thermal energy, comprising:

providing an energy source comprising deuterium gas, at least one cathode having an inert metal surface comprising palladium grains, and at least one anode having a metallic surface, and

producing a time-dependent electric potential between said at least one cathode and said at least one anode,

wherein said electric potential includes a repetitive higher-voltage pulse with a duration of from 0.1 to 40 microseconds superimposed upon a lower steady-state voltage, wherein said steady-state voltage is high enough to draw deuterium ions through the gas towards the cathode without producing ionization that would support sparking, and

wherein characteristics of the higher-voltage pulse are adjusted to control the average temperature of the cathode, and therefore the average rate of energy production of the source, and

transferring heat from the energy source to a heat-receiving element, whereby useful thermal energy is produced.

24. The method of claim 23, wherein the characteristics of the higher-voltage pulse that are adjusted to control the average temperature of the cathode include at least one characteristic selected from the group consisting of amplitude, rate, and duration of the higher voltage pulse.

25. The method of claim 23, further comprising the step of

converting thermal energy in the heat-receiving element to electrical or mechanical energy.

26. A controlled method of producing useful thermal energy comprising:

a. providing at least one cathode comprising palladium grains of uniform thickness in the range of about 0.1 to about 200 microns formed on or attached to a conducting metal element;

b. enclosing said at least one cathode and at least one anode in a chamber;
c. filling the chamber with deuterium gas;
d. exposing the cathode to a current of deuterium ions to increase the ratio of the number of deuterons to the number of palladium atoms to greater than about 0.7;
e. increasing the concentration of deuterium in the grains to support a polyplasmon field;
f. supplying a time-dependent differential voltage between the at least one cathode and the at least one anode to initiate and sustain a nuclear reaction, wherein said voltage pulse is high enough and has sufficient current multiplied by time duration to initiate a nuclear chain reaction in the palladium-deuterium surface of the cathode;
g. bombarding the grains with deuterium ions in order to create polyplasmons with energies in excess of 783 keV;
h. maintaining a constant lower voltage between pulses in order to maintain a high concentration of deuterium in the grains, whereby a low-energy nuclear chain reaction is initiated, whereby high-temperature heat is produced in the chamber; and
i. collecting the high-temperature heat via a heat collection system.

27. The method of claim 26, wherein the voltage pulses are between about 10 and 100 V.

28. The method of claim 26, further comprising the step of converting the high-temperature heat via a thermoelectric converter into usable electric energy.

29. The method of claim 26, further comprising the step of using the high-temperature heat to drive a steam engine, steam turbine, or gas turbine to produce mechanical power.

30. The method of claim 29, further comprising the step of using said mechanical power to power a generator to generate electricity.

31. A method of producing grains for a cold fusion cathode comprising the steps;
   a. polishing a support plate of a non-reacting metal to a mirror finish,
   b. depositing a thin, uniform film of a surface metal having a uniform thickness between about 0.1 to about 200 microns,
   c. cutting the surface layer into single crystalline grains of dimensions of about 0.5 to 200 microns separated from each other by the width of the cut, whereby the grains retain a relatively high concentration of dissolved deuterium.

32. The method of claim 31 wherein said depositing is done by electroplating, vapor deposition (sputtering), chemical vapor deposition, or any other method that results in a film of uniform thickness.

33. The method of claim 31 wherein the grains are cut into squares, rectangles, or other geometric shapes that are adapted to support a standing wave that is the coherent polyplasmon.

34. The method of claim 31 further comprising the further step of introducing onto the support plate 1 to 100 monolayers of a different chemical element, such as manganese, to insure that the boundary at the interface between the support plate and the metal grains has high internal reflectivity for the plasmon while retaining adequate conductivity to utilize the generated electricity.

35. A method of producing grains for a cold fusion cathode, by masking techniques, comprising the steps of:
   a. polishing a support plate of a non-reacting metal to a mirror finish,

b. using photoresist technology to mask the space on the support plate required for separating the grains,

c. depositing a thin film of a surface metal having a substantially uniform thickness on the support plate wherein crystalline grains are formed on the masked and unmasked portions of the support plate, and

d. dissolving the photoresist mask, whereby crystalline grains are removed from the previously-masked areas of the support plate while remaining on the previously-unmasked areas.

36.A cathode with an active surface comprising a plurality of separate, closely spaced grains prepared by the method of claim 31.

37.A cathode with an active surface comprising a plurality of separate, closely spaced grains prepared by the method of claim 35.

FIGURE 1

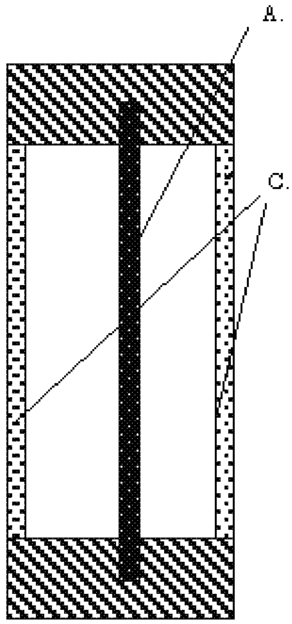


FIGURE 2

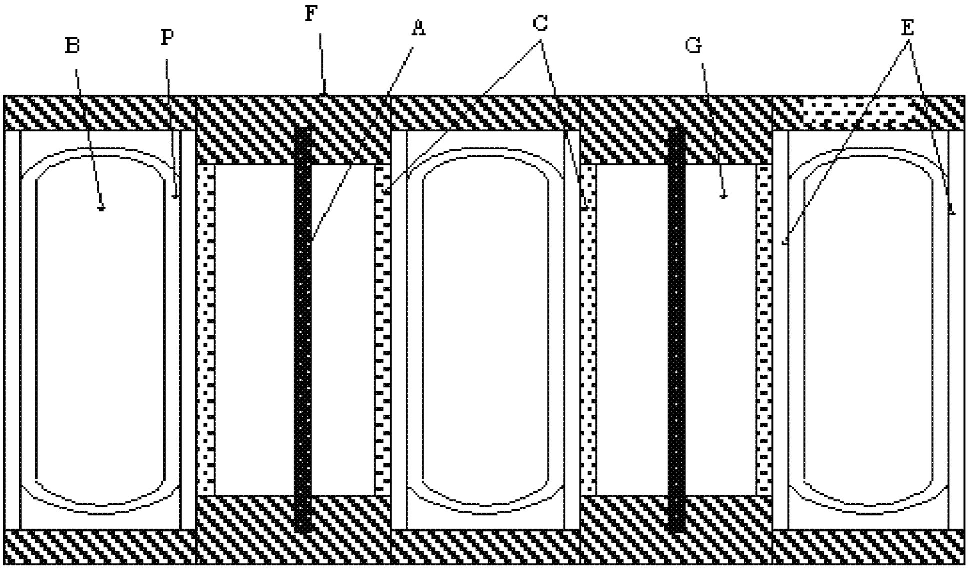


FIGURE 3

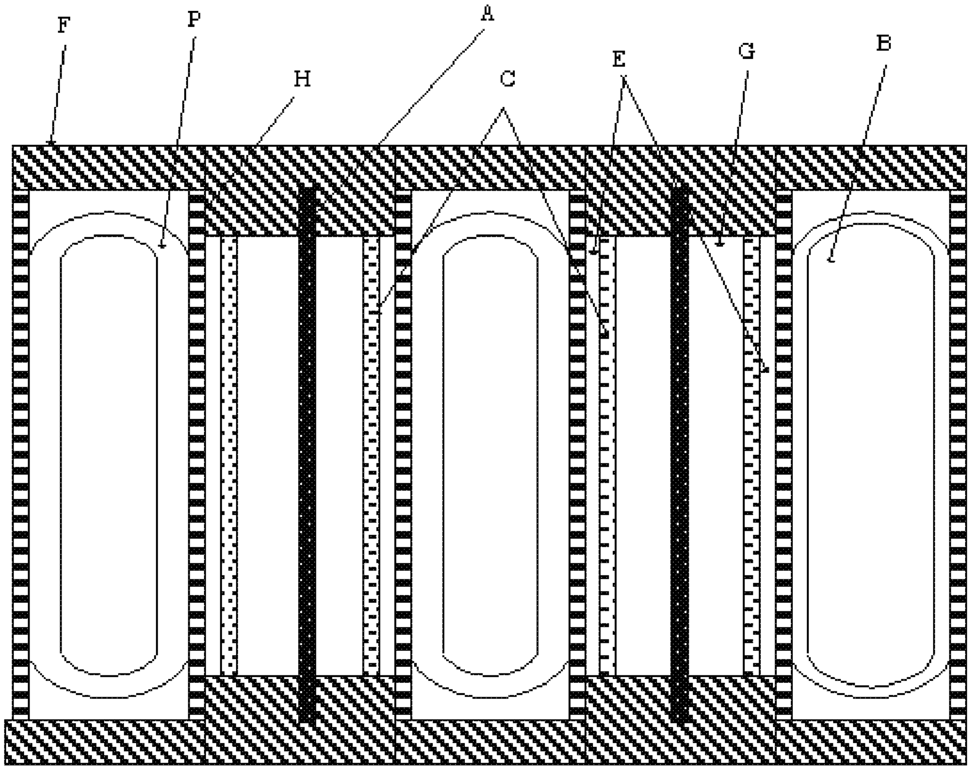


FIGURE 4

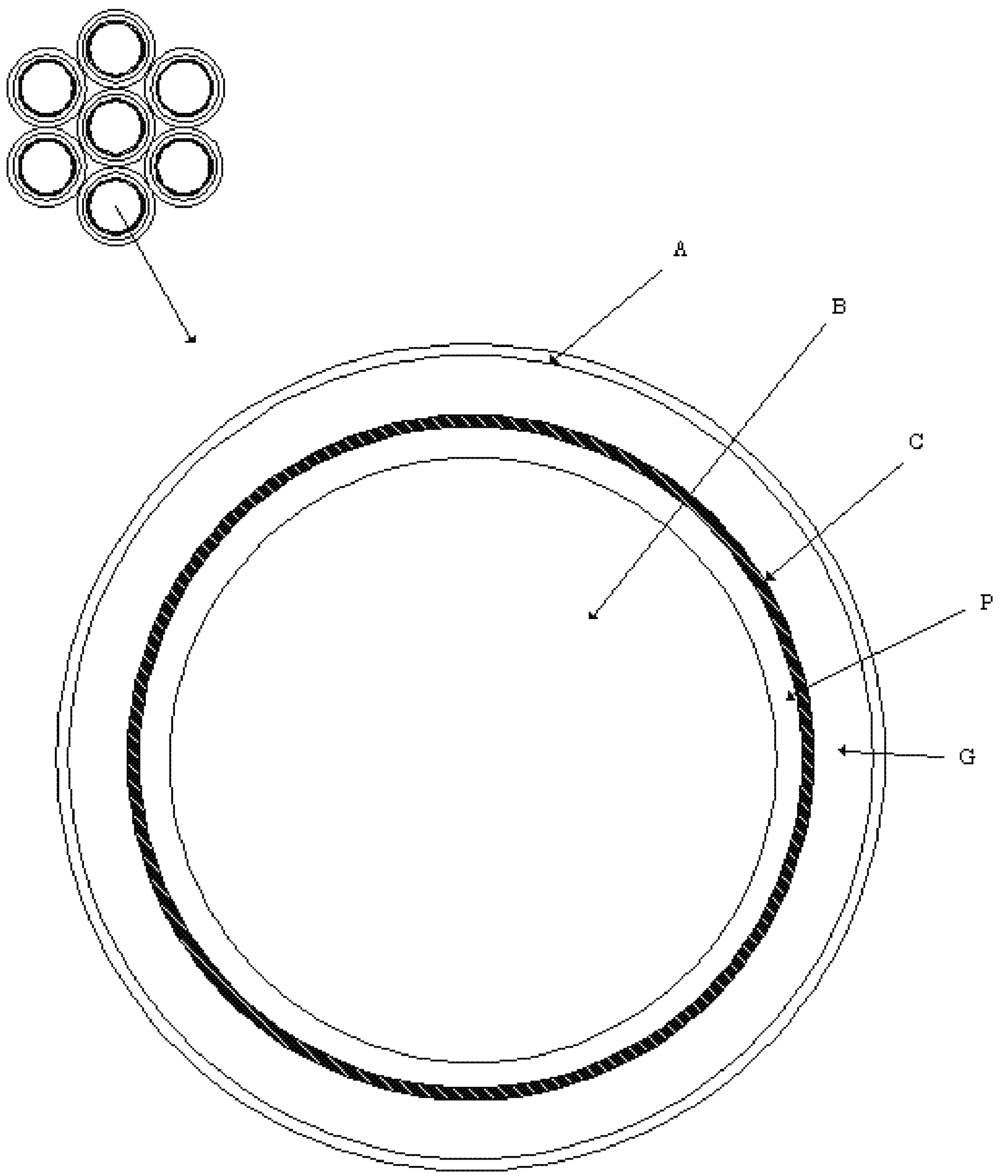


FIGURE 5

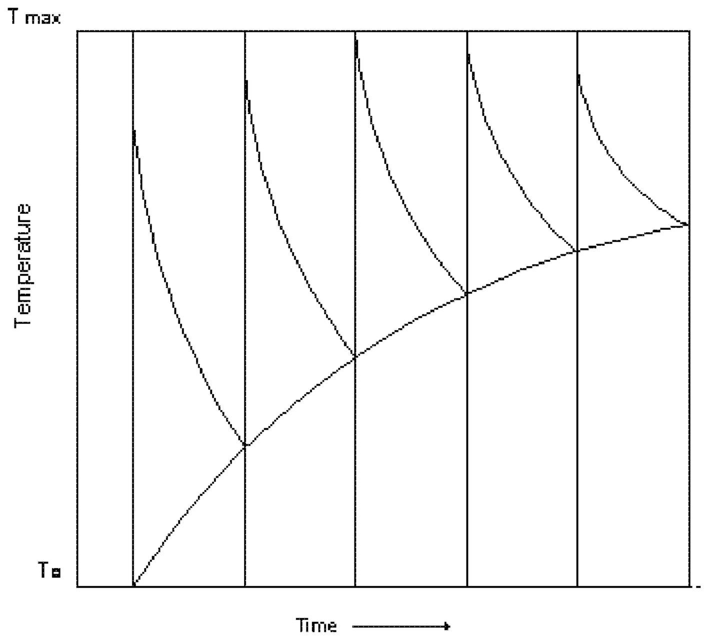


FIGURE 6

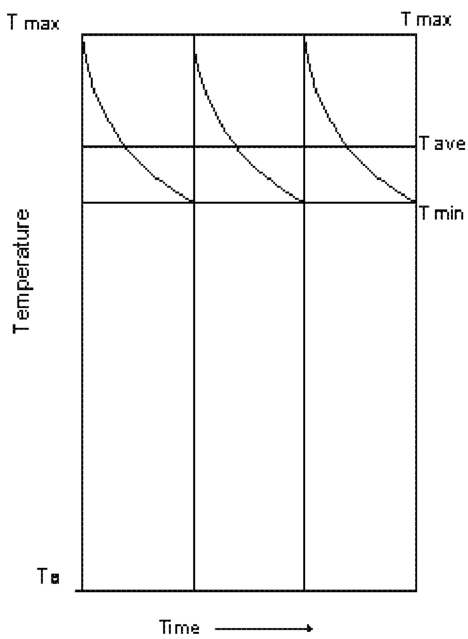
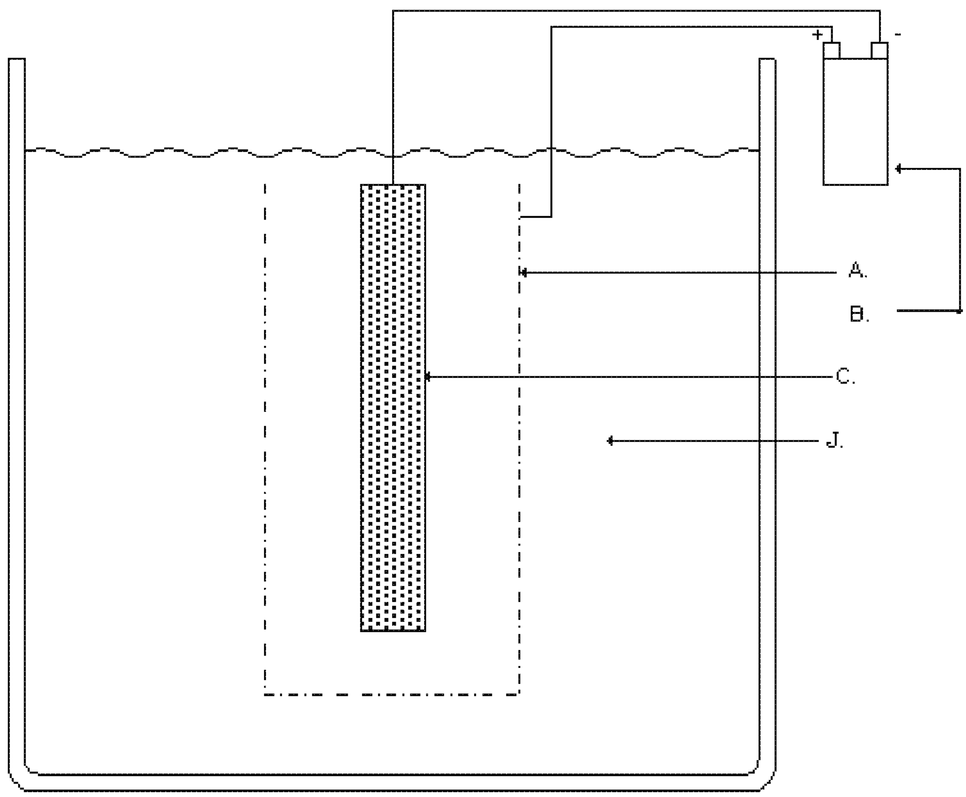


FIGURE 7



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/052619

A. CLASSIFICATION OF SUBJECT MATTER

G21B 3/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G21B 3/00, B23K 10/00, G21B 1/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords cold fusion, plasma, nuclear reaction

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No
A	CA 2621914-A1 (PURRATIO AG) 09 August 2006 See claim 1 and figure 1	1-37
A	KR 10-2001-0111064 A (KANG, KYUNG CHANG) 15 December 2001 See claims 4 - 6 and figure 2	1-37
A	EP 0463089 Bl (UNIVERSITY OF UTAH RESEARCH FOUNDATION) 22 May 1996 See the whold documents	1-37

☐ Further documents are listed in the continuation of Box C

☒ See patent family annex

* Special categories of cited documents
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 JUNE 2010 (11 06 2010)	11 JUNE 2010 (11.06.2010)

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Facsimile No 82-42-472-7140	Telephone No 82-42-481-8454

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