Abstract:

An apparatus and a method for in-vivo power generation

An apparatus for an in-vivo power generation comprises a fuel convertor for converting glucose in the cerebrospinal fluid (CSF) to a hydrogen rich, low carbon fuel such as ethanol or methanol by the action of a bioenzyme on the glucose in the CSF. The apparatus further comprises a biofuel cell comprising a cathode chamber and an anode chamber with a membrane assembly sandwiched between them. The membrane assembly comprises a cathode, an anode and a proton exchange membrane. The cathode is coated with an enzyme laccase, which enables extraction of oxygen when the CSF is passed through the cathode chamber. The oxygen from the cathode chamber and the hydrogen in the hydrogen rich fuel from the anode chamber diffuses through the proton exchange membrane and reacts at an ionic level to result in water and electrical power.

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We Claim:

1. An apparatus for in-vivo power generation comprising:

a fuel generator arranged to produce a hydrogen rich fuel from a body fluid flowing through the fuel generator; and

a biofuel cell comprising a first chamber and a second chamber separated by a membrane assembly, wherein a first electrode in the membrane assembly comprises a catalyst for enabling extracting oxygen from the body fluid, the body fluid being configured to flow through the first chamber and wherein the second chamber is arranged to receive the hydrogen rich fuel from the fuel generator,

wherein, when in use, electrical power is generated when the oxygen from the first chamber and hydrogen in the hydrogen rich fuel from the second chamber respectively combine reactively.

2. The apparatus for in-vivo power generation as claimed in claim 1, wherein the fuel generator is a low carbon fuel convertor which is configured to receive the body fluid and produce the hydrogen rich fuel by the action of a bioenzyme on glucose in the body fluid.

3. The apparatus for in-vivo power generation as claimed in claim 2, wherein the body fluid is cerebro spinal fluid.

4. The apparatus for in-vivo power generation as claimed in claim 3, wherein in the hydrogen rich fuel, a quantity of hydrogen is greater than a quantity of carbon.

5. The apparatus for in-vivo power generation as claimed in claim 1, wherein the first electrode is a cathode.

6. The apparatus for in-vivo power generation as claimed in claim 5, wherein the catalyst is laccase.

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7. The apparatus for in-vivo power generation as claimed in claim 1, wherein the hydrogen rich fuel is one of ethanol and methanol.

8. The apparatus for in-vivo power generation as claimed in claim 2, wherein the bioenzyme is one of pectine methyl esterase and zymase.

9. The apparatus for in-vivo power generation as claimed in claim 1, wherein the bio fuel cell is a nano scale device.

10. The apparatus for in-vivo power generation as claimed in claim 1, wherein the membrane is nafion.

11. The apparatus for in-vivo power generation as claimed in claim 10, wherein a thickness of the membrane is 100nm.

12. The apparatus for in-vivo power generation as claimed in claim 1, further comprising a packaging for the bio fuel cell, the packaging composed of bio compatible material.

13. The apparatus for in-vivo power generation as claimed in claim 12, wherein the bio compatible material comprises bio glass, the bio glass coated with polydimethylsiloxane.

14. A method for in-vivo power generation using an in-vivo power generation apparatus comprising a fuel generator and a bio fuel cell, wherein the biofuel cell comprises a first chamber and a second chamber and a membrane assembly disposed between the first chamber and the second chamber, the method comprising:

generating a hydrogen rich fuel from a body fluid by passing the body fluid through the fuel generator;

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extracting oxygen from the body fluid by passing the body fluid through the first chamber of the bio fuel cell, wherein a catalyst in a first electrode in the membrane assembly enables extracting oxygen from the body fluid;

passing the hydrogen rich fuel through the second chamber in the bio fuel cell; and

generating electrical power by a reaction occurring across the membrane assembly in the bio fuel cell, the reaction occurring between the oxygen and hydrogen in the hydrogen rich fuel, from the first chamber and the second chamber respectively.

15. The method for in-vivo power generation as claimed in claim 14, wherein generating the hydrogen rich fuel from the body fluid by passing the body fluid through the fuel generator comprises generating the hydrogen rich fuel from the body fluid by passing the body fluid through a low carbon fuel convertor.

16. The method for in-vivo power generation as claimed in claim 14, wherein the body fluid is cerebro spinal fluid.

17. The method for in-vivo power generation as claimed in claim 16, wherein generating the hydrogen rich fuel from the cerebro spinal fluid by passing the cerebro spinal fluid through the low carbon fuel convertor comprises utilizing a bioenzyme in the low carbon fuel convertor to act on glucose in the cerebro spinal fluid to generate the hydrogen rich fuel.

18. The method for in-vivo power generation as claimed in claim 17, wherein the bioenzyme is one of pectine methyl esterase and zymase.

19. The method for in-vivo power generation as claimed in claim 17, wherein in the hydrogen rich fuel, a quantity of hydrogen is greater than a quantity of carbon.

20. The method for in-vivo power generation as claimed in claim 19, wherein the hydrogen rich fuel is one of ethanol and methanol.

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21. The method for in-vivo power generation as claimed in claim 14, wherein the catalyst is laccase.

22. The method for in-vivo power generation as claimed in claim 14, wherein the membrane is nafion.

23. The method for in-vivo power generation as claimed in claim 22, wherein the thickness of the membrane is 100nm.

Dated 28th of August 2013

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(Authorized Patent Agent for the Applicant)

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Title:

An apparatus and a method for in-vivo power generation

Field of the Invention:

The present invention relates generally to an apparatus and method for in-vivo power generation. More specifically, the present invention relates to a biofuel cell using cerebrospinal fluid for electrical power generation.

Background:

The numbers of body implants have shown an exponential increase in their use. The traditional power sources used in the implants are lithium ion button batteries which need to be frequently recharged, and have a short lifetime of 2 years to 3 years and to replace them a surgery is required every time. These batteries also result in toxic contamination inside the body and the resulting in fatalities.

US 2006/0020239 A1delineates a cerebrospinal fluid (CSF) flow sensing device for sensing CSF flow through an implantable ventricular shunt. The sensing device is implanted within the CSF shunt, and includes a flow sensor to sense flow rate or shunt blockage. The sensing device is either placed within or adjacent the fluid path through the shunt. The sensing device transmits and sends the flow rate to an external monitoring device by wireless telemetry. The sensing device may be integrally formed as part of the shunt, or clamped onto apportion of the shunt, in which case the sensing device may be reusable. An external monitor receives the transmitted flow signal and presents information based on the flow signal. The disadvantage of the

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above described device is that the device has to be inductively powered or has to have its own power supply.

There is therefore a need to mitigate the disadvantages associated with the devices explained above.

Objective of the Invention:

1. To achieve a power source which is biocompatible and used for in-vivo applications in the human body.

2. To achieve a nano scale biofuel cell with high power output and high efficiency

3. To achieve using glucose present in the cerebrospinal fluid for generation of electrical power

Summary:

According to one aspect of the invention, there is disclosed an apparatus for in-vivo power generation. The apparatus comprises a fuel generator arranged to produce a hydrogen rich fuel from a body fluid flowing through the fuel generator. The apparatus further comprises a biofuel cell comprising a first chamber and a second chamber separated by a membrane assembly, wherein a first electrode in the membrane assembly comprises a catalyst for enabling extracting oxygen from the body fluid, the body fluid being configured to flow through the first chamber and wherein the second chamber is arranged to receive the hydrogen rich fuel from the fuel generator. Electrical power is generated when the oxygen from the first chamber and hydrogen in the hydrogen rich fuel from the second chamber combine reactively.

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According to another aspect of the invention, there is disclosed a method for in-vivo power generation using an in-vivo power generation apparatus comprising a fuel generator and a biofuel cell, wherein the biofuel cell comprises a first chamber and a second chamber and a membrane assembly disposed between the first chamber and the second chamber. The disclosed method comprises generating a hydrogen rich fuel from a body fluid by passing the body fluid through the fuel generator. The method further comprises extracting oxygen from the body fluid by passing the body fluid through the first chamber of the biofuel cell, wherein a catalyst in a first electrode in the membrane assembly enables extracting oxygen from the body fluid. The method further comprises passing the hydrogen rich fuel through the second chamber in the biofuel cell. The method further comprises generating electrical power by a reaction occurring across the membrane assembly in the biofuel cell, the reaction occurring between the oxygen from the first chamber and hydrogen in the hydrogen rich fuel from the second chamber.

Brief Description of Drawings:

Figure 1 is a schematic illustration of an apparatus for in-vivo power generation

Figure 2 is a schematic illustration of a bio fuel cell of the apparatus for in-vivo power generation of Figure 1

Figure 3 is a flowchart showing the process steps for a method of in-vivo power generation in an in-vivo power generation apparatus

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Detailed Description:

Figure 1 is a schematic illustration of an apparatus 100 for in-vivo power generation. As illustrated in Figure 1, the apparatus 100 for in-vivo power generation is used for powering medical implants inside human bodies and animals. The apparatus 100 uses raw materials for power generation from inside human bodies and animals, as will be described hereinafter.

The apparatus 100 comprises a fuel generator 10 and a biofuel cell 15. The fuel generator 10 is arranged to produce a hydrogen rich fuel from a body fluid flowing through the same. The fuel generator 10 can be a low carbon fuel convertor which is configured to receive the body fluid and produce the hydrogen rich fuel by the action of a bioenzyme on glucose in the body fluid. The body fluid that is fed and arranged to flow through the fuel generator 10 is cerebrospinal fluid (CSF). CSF is a clear and colorless bodily fluid produced in the choroid plexus of the brain. CSF contains glucose and the apparatus 100 is arranged to use the glucose in the CSF to generate power. The glucose in CSF is D-glucose and the concentration of D-glucose in CSF is 400 – 850 mg/L. The fuel generator 10 is arranged to receive the CSF through a shunt tube 20 from a vessel in the human body that carries CSF. The shunt is a passage which allows movement of any fluid from one part of the body to another. The shunt tube 20 enables movement of CSF to the fuel generator 10. The shunt tube 20 can also be referred to as a cerebral shunt as the shunt tube 20 carries CSF.

The low carbon fuel convertor which is the fuel generator 10 comprises a bioenzyme, which can be any one of pectine methyl esterase (PME) and zymase (yeast). Enzymes are biological molecules responsible for a multitude of chemical interconversions that are important for biological life. Among many biological functions carried out by enzymes in humans, some of them are the digestion of food and synthesis of DNA.

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The action of pectine methyl esterase on CSF flowing through the fuel generator 10 yields methanol. The chemical formula of methanol is CH_3OH. It is apparent that methanol comprises 4 hydrogen atoms and 1 carbon atom. The hydrogen-carbon ratio which is depicted by H/C ratio is 4:1 for methanol. The action of zymase on CSF flowing through the fuel generator 10 yields ethanol. The chemical formula of ethanol is C_2H_5OH. The reaction that occurs in the fuel generator 10 to convert glucose to ethanol using zymase is as follows:

$$C_6H_{12}O_6\ (aq) \xrightarrow{zymase} 2C_2H_5OH\ (aq) + 2CO_2\ (g)$$

It is apparent that ethanol comprises 6 hydrogen atoms and 2 carbon atoms. The H/C ratio for ethanol is 6:2. It is apparent that both in ethanol and methanol, the hydrogen content is greater than the carbon content and that forms the reason for ethanol and methanol to be referred to as a hydrogen rich fuel or a low carbon fuel.

Figure 2 is a schematic illustration of a biofuel cell of the apparatus 100. As illustrated in Figure 2, the biofuel cell 15 comprises a first chamber 25 and a second chamber 30, separated by a membrane assembly 35. The first chamber 25 is a cathode chamber. The second chamber 30 is an anode chamber. The first chamber 25 comprises a first chamber entrance 26 and a first chamber exit 27. As illustrated in Figure 1, a tube 40 departs from the shunt tube 20 carrying the body fluid or the CSF directly to the first chamber entrance 26 of the first chamber 25 of the biofuel cell 15. The shunt tube 20 is composed of silicone material. The tube 40 can also be referred to as a cathode chamber nanochannel.

The second chamber 30 or the anode chamber is arranged to receive the hydrogen rich fuel from the fuel generator 10 through a second chamber entrance 31. The hydrogen rich fuel is transported from the fuel generator 10 to the second chamber 30 through an anode chamber nanochannel 45 as illustrated in Figure 1. As illustrated in

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Figure 2, the membrane assembly 35 is an assembly comprising a first electrode 36, a second electrode 37 and a membrane 38. The first electrode 36 is a porous gas diffusion electrode (cathode) 36 and the second electrode 37 is a porous gas diffusion electrode (anode). The membrane 38 is a proton exchange membrane. The porous gas diffusion electrode (cathode) 36 can also be referred to as a cathode 36 for the purposes of explanation. The porous gas diffusion electrode (anode) 37 can also be referred to as an anode 37 for the purposes of explanation. The proton exchange membrane 38 can also be referred to as a polymer electrolyte membrane and is a semipermeable membrane, which is understood by a person skilled in the art. The proton exchange membrane 38 is disposed between the cathode 36 and the anode 37 forming a sandwich like structure. The proton exchange membrane comprises nafion, which is a sulfonated tetrafluoroethylene based fluoropolymer-copolymer. Nafion is used as a proton conductor in the proton exchange membrane. As described above, the cathode 36 and the anode 37 form part of the membrane assembly 35. The cathode 36 is open to a cavity (not shown in Figures) of the cathode chamber 25 and the anode 37 is open to a cavity (not shown in Figures) of the anode chamber 30. Both the cathode 36 and the anode 37 are made of Raney-platinum film. The cathode 36 is coated with a catalyst, which is capable of extracting oxygen from the body fluid which is CSF, when the body fluid flows through the cavity of the first chamber 25. The body fluid enters the first chamber 25 through the first chamber entrance 26 and as the body fluid flows along the first chamber 25, oxygen is extracted from the body fluid by the action of the catalyst laccase coated on the cathode. The oxygen generated in the first chamber 25 and the hydrogen from the hydrogen rich fuel in the second chamber 30 combine reactively across the membrane assembly 35 to result in a flow of electrons resulting in electricity. To elaborate, firstly the hydrogen ionizes and then diffuses through the proton exchange membrane 38 to combine with oxygen to form water. The half-cell reactions taking place are:

Anode: $H_2 + O^{-2} \longrightarrow H_2O + 2e^-$

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Cathode: $\frac{1}{2}O_2 + 2e^- \longrightarrow O^{-2}$

Overall: $H_2 + \frac{1}{2}O_2 \longrightarrow H_2O$

In the anode chamber 30, electrons are stripped from the hydrogen atoms at the anode 37. The positively charged hydrogen ions (protons) then pass through the proton exchange membrane 38 to the cathode 36, where they react with the oxygen and the stripped electrons to form water. The flow of electrons from the anode 37 to the cathode 36 results in electrical power to be supplied to in-vivo devices.

As illustrated in Figure 2, the biofuel cell 15 is elongated with the first chamber 25, the second chamber 30 and the membrane assembly 35 between the first chamber 25 and the second chamber 30 being elongated. The first chamber entrance 26 and the second chamber entrance 31 are disposed at opposite ends of the biofuel cell 15, such that the body fluid entering the first chamber entrance 26 and flowing through the first chamber 25 and the hydrogen rich fuel entering the second chamber entrance 31 and flowing through the second chamber 30 flow in opposite directions in the biofuel cell 15. As illustrated in Figure 1, the body fluid flowing out from the first chamber 25 and from which oxygen has been extracted flows out through a first nanochannel 50 to an exit nanochannel 55 through an intermediate nanochannel 60. The compositional remnants of the body fluid from which hydrogen rich fuel has been generated in the fuel generator 10 passes to the exit nanochannel 55 through a second nanochannel 65. The compositional remnants of the hydrogen rich fuel from which hydrogen is extracted in the second chamber 30 along with water flows out through a third nanochannel 70. The third nanochannel 70 connects to the intermediate nanochannel 60 and drains into the intermediate nanochannel 60. The second nanochannel 65 from the fuel generator 10 and the intermediate nanochannel 60 meet and form the exit nanochannel 55. The exit nanochannel 55 drains into the abdominal cavity of the human being inside which the apparatus 100 is implanted.

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The spatial and positional orientation of the apparatus 100 as illustrated in Figure 1 enables the CSF to flow through the fuel generator 10 to produce the hydrogen rich fuel and the hydrogen rich fuel to flow through the second chamber 30 and the CSF directly through the first chamber 25 naturally aided by gravity, without the necessity for any powered fluid pumps. The oxygen and hydrogen in the cathode chamber 25 and the anode chamber 30 which is in gaseous form will be higher in volume when compared to the liquid form and will naturally be driven to diffuse through the membrane assembly 35, therefore running the biofuel cell 15.

In an exemplary embodiment of the apparatus 100, a width and a height of the first chamber 25 and the second chamber 30 are 500 nm and 500 nm respectively. A thickness of the cathode and the anode are 100 nm and 100 nm respectively. A length of the first chamber 25, the second chamber 30 and the membrane assembly 35 are 1000 nm, 1000 nm and 1000 nm respectively. A thickness of the membrane 38 is 100 nm. It is thus apparent from the above that the biofuel cell 15 is a nano-scale device and can thus be effectively and conveniently implanted in the human body.

As illustrated in Figure 1, the apparatus 100 further comprises a packaging 75, the packaging composed on a bio compatible material such as bio glass. The chemical formula for bio glass is Na_2O-CaO-SiO_2-P_2O_5. The bio glass in the packaging 75 can be coated with polydimethysiloxane (PDMS). PDMS belongs to a group of polymeric organosilicon compounds. PDMS is optically clear, inert, non-toxic and non-flammable. PDMS is also referred to as silicone. The above mentioned properties of PDMS enable PDMS to be coated on the packaging 75 which is implanted inside the human body without any deleterious effects to the human body. The bio glass packaging provides sturdy support to the package. The coating of PDMS as described above provides protection for the bio glass packaging 75 from various in-vivo forces. In other words, the coating of silicone reduces the brittleness of the packaging 75.

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The bio compatible material is not limited to what has been described above and can include other similar materials as well.

Figure 3 is a flowchart showing the process steps for a method 200 of in-vivo power generation using the in-vivo power generation apparatus 100. As illustrated in Figure 3, the method 200 comprises a step 210 of generating the hydrogen rich fuel from the body fluid by passing the body fluid through the fuel generator 10, which has already been described earlier. The method 200 further comprises a step 220 of extracting oxygen from the body fluid by passing the body fluid through the first chamber 25 of the biofuel cell 15. The first electrode in the membrane assembly 35 is coated with a catalyst which enables extracting oxygen from the body fluid. A further step 230 comprises passing the hydrogen rich fuel through the second chamber 30 in the biofuel cell 15. The method 200 comprises a further step 240 which comprises generating power by a reaction occurring across the membrane assembly 35, the membrane assembly 35 separating the first chamber 25 and the second chamber 30. The reaction occurs between the oxygen from the first chamber 25 and the hydrogen in the hydrogen rich fuel from the second chamber 30. The step 210 comprises utilizing a bioenzyme in the fuel generator 10 or the low carbon fuel convertor to act on glucose in the body fluid or CSF to generate the hydrogen rich fuel, which can be one of ethanol and methanol.

The apparatus 100 for in-vivo power generation can be fabricated on a chip which can be implanted in the human body. The lifetime of the apparatus 100 described above can be 40000 to 60000 hours.

The CSF that is used in the apparatus 100 and the method 200 can be any one of waste CSF and utilizable CSF. Waste CSF is CSF that is being drained out from the cerebral region through the thorax into the abdomen of the human body or the animal after being utilized in the cerebral region. Utilizable CSF is the CSF in the brain and

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which is still being utilized in the cerebral region. The apparatus 100 and method 200 can be implanted and employed in any part of the human body and animal and therefore utilizes CSF that is waste CSF or utilizable CSF depending on the implanted location.

It is to be understood that the foregoing description is intended to be purely illustrative of the principles of the disclosed techniques, rather than exhaustive thereof, and that changes and variations will be apparent to those skilled in the art, and that the present invention is not intended to be limited other than as expressly set forth in the following claims.

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We Claim:

1. An apparatus for in-vivo power generation comprising:

a fuel generator arranged to produce a hydrogen rich fuel from a body fluid flowing through the fuel generator; and

a biofuel cell comprising a first chamber and a second chamber separated by a membrane assembly, wherein a first electrode in the membrane assembly comprises a catalyst for enabling extracting oxygen from the body fluid, the body fluid being configured to flow through the first chamber and wherein the second chamber is arranged to receive the hydrogen rich fuel from the fuel generator,

wherein, when in use, electrical power is generated when the oxygen from the first chamber and hydrogen in the hydrogen rich fuel from the second chamber respectively combine reactively.

2. The apparatus for in-vivo power generation as claimed in claim 1, wherein the fuel generator is a low carbon fuel convertor which is configured to receive the body fluid and produce the hydrogen rich fuel by the action of a bioenzyme on glucose in the body fluid.

3. The apparatus for in-vivo power generation as claimed in claim 2, wherein the body fluid is cerebro spinal fluid.

4. The apparatus for in-vivo power generation as claimed in claim 3, wherein in the hydrogen rich fuel, a quantity of hydrogen is greater than a quantity of carbon.

5. The apparatus for in-vivo power generation as claimed in claim 1, wherein the first electrode is a cathode.

6. The apparatus for in-vivo power generation as claimed in claim 5, wherein the catalyst is laccase.

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7. The apparatus for in-vivo power generation as claimed in claim 1, wherein the hydrogen rich fuel is one of ethanol and methanol.

8. The apparatus for in-vivo power generation as claimed in claim 2, wherein the bioenzyme is one of pectine methyl esterase and zymase.

9. The apparatus for in-vivo power generation as claimed in claim 1, wherein the bio fuel cell is a nano scale device.

10. The apparatus for in-vivo power generation as claimed in claim 1, wherein the membrane is nafion.

11. The apparatus for in-vivo power generation as claimed in claim 10, wherein a thickness of the membrane is 100nm.

12. The apparatus for in-vivo power generation as claimed in claim 1, further comprising a packaging for the bio fuel cell, the packaging composed of bio compatible material.

13. The apparatus for in-vivo power generation as claimed in claim 12, wherein the bio compatible material comprises bio glass, the bio glass coated with polydimethylsiloxane.

14. A method for in-vivo power generation using an in-vivo power generation apparatus comprising a fuel generator and a bio fuel cell, wherein the biofuel cell comprises a first chamber and a second chamber and a membrane assembly disposed between the first chamber and the second chamber, the method comprising:

generating a hydrogen rich fuel from a body fluid by passing the body fluid through the fuel generator;

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extracting oxygen from the body fluid by passing the body fluid through the first chamber of the bio fuel cell, wherein a catalyst in a first electrode in the membrane assembly enables extracting oxygen from the body fluid;

passing the hydrogen rich fuel through the second chamber in the bio fuel cell; and

generating electrical power by a reaction occurring across the membrane assembly in the bio fuel cell, the reaction occurring between the oxygen and hydrogen in the hydrogen rich fuel, from the first chamber and the second chamber respectively.

15. The method for in-vivo power generation as claimed in claim 14, wherein generating the hydrogen rich fuel from the body fluid by passing the body fluid through the fuel generator comprises generating the hydrogen rich fuel from the body fluid by passing the body fluid through a low carbon fuel convertor.

16. The method for in-vivo power generation as claimed in claim 14, wherein the body fluid is cerebro spinal fluid.

17. The method for in-vivo power generation as claimed in claim 16, wherein generating the hydrogen rich fuel from the cerebro spinal fluid by passing the cerebro spinal fluid through the low carbon fuel convertor comprises utilizing a bioenzyme in the low carbon fuel convertor to act on glucose in the cerebro spinal fluid to generate the hydrogen rich fuel.

18. The method for in-vivo power generation as claimed in claim 17, wherein the bioenzyme is one of pectine methyl esterase and zymase.

19. The method for in-vivo power generation as claimed in claim 17, wherein in the hydrogen rich fuel, a quantity of hydrogen is greater than a quantity of carbon.

20. The method for in-vivo power generation as claimed in claim 19, wherein the hydrogen rich fuel is one of ethanol and methanol.

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21. The method for in-vivo power generation as claimed in claim 14, wherein the catalyst is laccase.

22. The method for in-vivo power generation as claimed in claim 14, wherein the membrane is nafion.

23. The method for in-vivo power generation as claimed in claim 22, wherein the thickness of the membrane is 100nm.

Dated 28th of August 2013

MAHUA ROY CHOWDHURY

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Applicant Name: IIT, BOMBAY

Sheet No: 01

Total No. of Sheets: 03

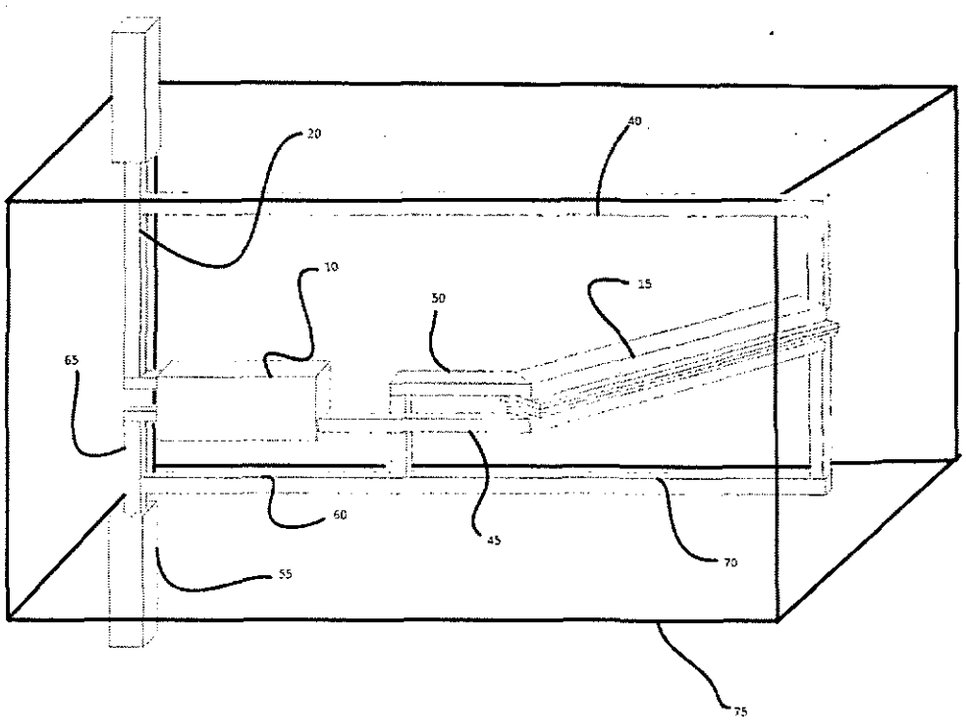

Figure-1

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Sheet No: 02

Total No. of Sheets: 03

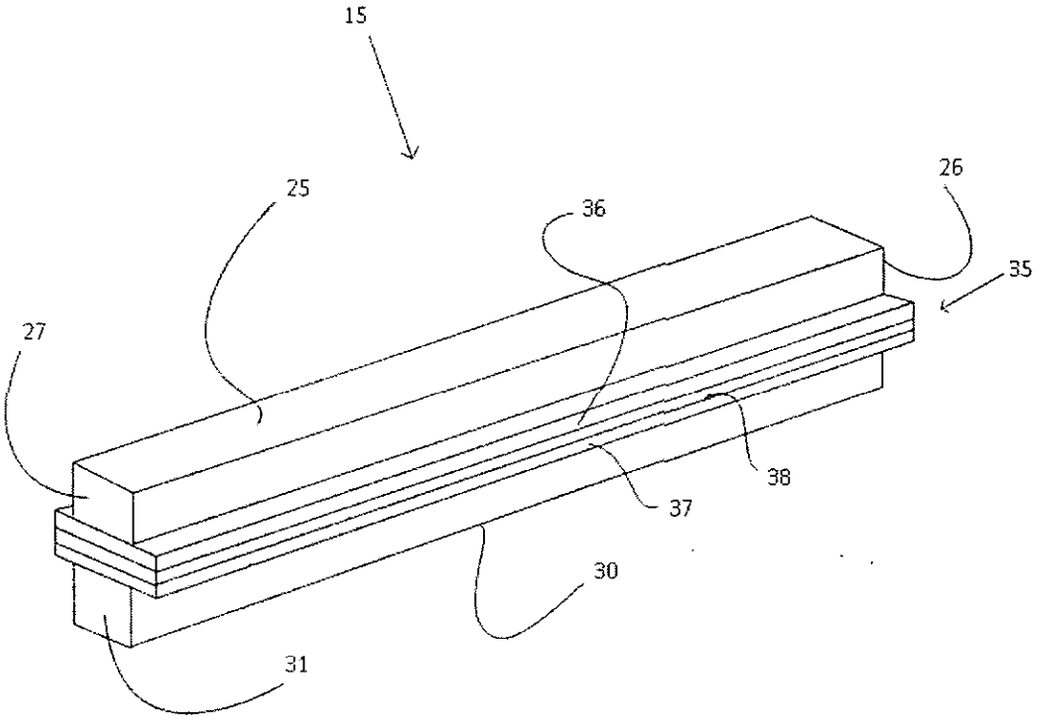

Figure-2

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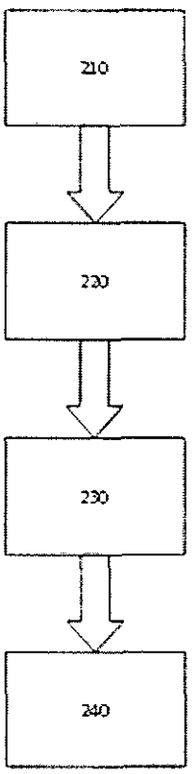

Figure-3

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