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COMPLETE SPECIFICATION
(See section 10 and rule 13)

TITLE

OSMOTIC POWER GENERATION SYSTEM

INVENTORS:

NANDIGANA, Vishal V.R. Indian Citizen
7-4-7, G2, SN Enclave, Sesha Sai Street, Ramarao Peta, KAKINADA 533004, India
NAYAK, Pramoda Kumar Indian Citizen
D1-87, 1st Floor, Bonn Avenue, IIT Madras, Chennai-600036, India
KRISHNAN, Sivarama Indian Citizen
D-01-04. Bonn Avenue, IIT Madras, Chennai-600036, India
YADAV, Sharad Kumar Indian Citizen
Y 2 D 171, Trivenipuram, Jhunsi, Prayagraaj, Uttar Pradesh, India 211019
GOPALAKRISHNAN, Aswathy Indian Citizen
Kallekkattil, Kalladathur P.O, Palakkad, Kerala, India 679552

APPLICANTS

INDIAN INSTITUTE OF TECHNOLOGY MADRAS (IIT MADRAS)
Office of the Dean ICSR,
Chennai 600 036, India

THE FOLLOWING SPECIFICATION PARTICULARLY DESCRIBES THE INVENTION AND THE MANNER IN WHICH IT IS TO BE PERFORMED

OSMOTIC POWER GENERATION SYSTEM

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application is a complete specification of provisional patent application no. 201941034016 entitled “A SCALABLE MEMBRANE FOR POWER GENERATION, ENERGY STORAGE, ENERGY HARVESTING, ENERGY CONVERSION, LIQUID ELECTRONICS AND ARTIFICIAL BRAIN CREATION USING SALT AND WATER” filed on 23.08.2019.

FIELD OF THE INVENTION

[0002] The invention generally relates to renewable energy generation and in particular to an osmotic power generation system that uses a scalable porous membrane.

DESCRIPTION OF RELATED ART

[0003] Renewable energy is the need of the hour for the growing population. The present renewable energy sources are solar, wind, and tidal energy. These sources of energy are discontinuous which may cause problem in power generation and storage. Generating power using salinity gradients was started in 2009 and companies in Denmark and Netherlands started the technology but not on commercial scale.

[0004] An osmotic power generator using saltwater and freshwater separated by an osmotic membrane may be used to generate electricity in abundance as seawater is available in large quantities and may also be reused. The power generated is harvested, stored, and used in energy conversion devices like a fuel cell, water battery, and power generator. The membranes used are made with large variety of materials to obtain satisfactory results. The membranes are of organic, inorganic, biomimetic, polymeric, stimuli responsive, PH- responsive types. The types of materials membranes include boron nitride and aramid nanofibers. The batteries produced using the membrane, are renewable and non- toxic, unlike conventional batteries. The compositions and the method of preparation for the membranes vary for every membrane. The membranes are affected by the salinity, PH, concentration, temperature conditions in the osmotic power generation.

[0005] The patent EP3475567B1, discloses the process of osmotic power generation comprising an active membrane supported in housing for receiving electrolyte liquids from two chambers. US20090250392A, describes the method of power generation using semi-permeable porous and non-porous membranes in elevated osmotic pressure. The patent US10233098B2, discusses the method of desalination of saltwater using a free-standing single layer nanoporous graphene membrane having a first planar side in contact with saltwater and opposing the second side from which desalinated water exists. The patent application US20190224628A1, discloses a process of preparing porous graphene-based films having reduced graphene oxide with different zones of different porosity that are used in infiltration processes. The article, “Atom-Thick Membranes for Water Purification and Blue Energy Harvesting”, David Pakulski et al.(2019), Advanced Functional Materials, disclosed the method of water purification and harvesting of osmotic power from the saline gradient between saltwater and freshwater. “New avenues for the large scale harvesting of blue energy”, Alessandro Siira et al., Nature Reviews Chemistry, discusses current technologies for the conversion of blue energy and development of new classes of membranes combining considerations in nanoscale fluid dynamics and surface chemistry.

[0006] There is a need to generate low cost, eco-friendly, renewable energy that may be harvested and stored in a large scale. The invention discloses a membrane and an osmotic power generation system that addresses some of the drawbacks of existing methods.

SUMMARY OF THE INVENTION

[0007] In various embodiments an osmotic power generator system is disclosed. The system includes a housing, a porous scalable membrane having a first surface and a second surface placed within the housing, a first chamber disposed on the first surface of the membrane and having a first electrode and a first electrolyte and a second chamber disposed on the second surface of the membrane and comprising a second electrode and a second electrolyte. A load is connected between the first electrode and the second electrode.

[0008] In various embodiments the porous scalable membrane includes a first membrane that is selected from SiNx (Silicon nitride) or Cu (Copper) membrane and a monolayer graphene membrane is mounted on a surface of the first membrane. In various embodiments the first membrane and the monolayer graphene membrane have one or more pores. In various embodiments the system is configured to pass ions between the first and second surfaces of the porous membrane due to an osmotic gradient between the first and the second electrolytes to generate a difference in potential and an ionic current between the first and second electrodes.

[0009] In various embodiments a size of the pore in the monolayer membrane is in a range of 0.5mm to 2mm. In various embodiments a pore density is in a range of 4 to 7 pores in the scalable membrane of dimension 1cmx1cm. In various embodiments a thickness of the scalable membrane is in a range 16 to 20 µm. In various embodiments a thickness of the monolayer membrane is in a range 0.342 to 0.345 nm. In various embodiments the first electrolyte is salt water or sea water. In various embodiments the second electrolyte is fresh water or river water. In various embodiments the power generated is in the range of 58 to 70 mW/mm^2 of pore area. In various embodiments the pore area / a membrane area is in the range 0.025 to 0.88

[0010] This and other aspects are disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The invention has other advantages and features which will be more readily apparent from the following detailed description of the invention and the appended claims, when taken in conjunction with the accompanying drawings, in which:

[0012] FIG. 1 shows the schematic representation of osmotic power generation using salinity gradient.

[0013] FIG. 2A shows the porous membrane with multiple pores and an inter pore distance of λ.

[0014] FIG 3A shows Graphene/ Copper sheet showing 1mm single and multiple holes formed using Femtosecond laser.

[0015] FIG. 3B illustrates Graphene/ Copper sheet showing 2mm single and multiple holes formed using Femtosecond laser.

[0016] FIG. 4A illustrates the Scanning Electron Microscopy showing commercially available Graphene/Copper membrane.

[0017] FIG. 4B illustrates the Raman spectroscopic analysis for graphene in copper membrane.

[0018] FIG. 5A illustrates the potassium concentration for a single 1 mm pore in a graphene on copper membrane of size 1 cm by 1 cm.

[0019] FIG. 5B illustrates the potential concentration for a single 1 mm pore in a graphene on copper membrane of size 1 cm by 1 cm.

[0020] FIG. 6A illustrates the power in a scalable porous membrane with pore area with a single pore.

[0021] FIG. 6B illustrates the power in a scalable porous membrane with pore area with 4 pores.

[0022] FIG. 6C illustrates the power in a scalable porous membrane with pore area with 7 pores.

[0023] FIG. 6D illustrates the individual (potassium and chlorine) and total current (I_total) in a scalable porous membrane with pore area with a single pore.

[0024] Referring to the drawings, like numbers indicate like parts throughout the views.

DETAILED DESCRIPTION

[0025] While the invention has been disclosed with reference to certain embodiments, it will be understood by those skilled in the art, that various changes may be made and equivalents may be substituted without departing from the scope of the invention. In addition, many modifications may be made, to adapt to a particular situation or material to the teachings of the invention, without departing from its scope.

[0026] Throughout the specification and claims, the following terms take the meanings explicitly associated herein unless the context clearly dictates otherwise. The meaning of "a", "an", and "the" include plural references. The meaning of "in" includes "in" and "on." Referring to the drawings, like numbers indicate like parts throughout the views. Additionally, a reference to the singular includes a reference to the plural unless otherwise stated or inconsistent with the disclosure herein.

[0027] The invention in its various embodiments discloses an osmotic power generation system. The osmotic power generation system has a scalable porous membrane that has graphene. The system is capable of generating power when the membrane is kept in a concentration gradient.

[0028] In various embodiments, the invention discloses an osmotic power generation system **100** as shown in FIG. 1. The system includes a housing **101**, a scalable porous membrane **160** is placed within the housing such that the membrane **160** partitions the housing into a first chamber and a second chamber as shown in FIG. 1. The scalable porous membrane **160** includes a first membrane **170** selected from SiNx (Silicon nitride) or Cu (Copper) membrane as shown in FIG. 2A. A monolayer graphene membrane **180** is mounted on a surface of the first membrane **170** as shown in FIG. 2B. In various embodiments the first membrane **170** is mounted on the monolayer graphene membrane **180.** In various embodiments the membranes have one or more pores **182** as shown in FIG. 2B and FIG. 2C. In various embodiments the one or more pores on the membrane are punched using a femto second laser beam. The pores are made continuously from the monolayer graphene membrane to the first membrane. The pore size is in the range 0.5mm to 2mm. In various embodiments, the spacing between the pores **182** is ‘λ’. In various embodiments the pore density in the porous membrane is in a range of 4 to 7 pores in the scalable membrane of dimension 1cmx1cm. In various embodiments the thickness of the scalable membrane is in a range 16 to 20 µm, wherein the thickness of the monolayer graphene membrane **180** is in a range 0.342 to 0.345 nm. In various embodiments for a membrane area of 1cm×1cm the pore area / a membrane area is in the range 0.025 to 0.88.

[0029] In various embodiments the membrane has a first surface and a second surface. The chamber disposed on the first surface of the membrane is the first chamber. The first chamber **110** has a first electrode **130** and a first electrolyte **112**. In various embodiments the first electrolyte **112** is salt water or sea water. The chamber disposed on the second surface of the membrane is the second chamber. The second chamber **120** has a second electrode **140** and a second electrolyte **122**. In various embodiments the second electrolyte **122** is fresh water or river water. In various embodiments the system **100** is configured to pass ions between the first and second surfaces of the porous membrane due to an osmotic gradient between the first **112** and the second electrolytes **122** to generate a difference in potential to generate an ionic current between the first electrode **130** and second electrode **140**. In various embodiments a load **150** is connected between the first electrode **130** and the second electrode **140** and is configured to receive power from the system. In various embodiments the power generated is in the range of 58 to 70 mW/mm^2 of pore area. The power generation is scalable to large scale power generation as illustrated further in the examples.

[0030] The osmotic power generation system is useful for energy harvesting, energy storage and in energy conversion devices like fuel-cell, water battery and power generator. The battery is renewable and non-toxic. The fuel-cell is made with conventional fuel-cell set-up using the scalable porous membranes.

[0031] EXAMPLES:

[0032] Example. 1: Power generation in an Osmotic power generation system that uses graphene in copper membrane of varying dimensions:

[0033] An Osmotic power generation system was constructed. A graphene in copper membrane having pores as shown in FIG. 3A and FIG. 3B was kept between the first chamber and the second chamber. Scanning electron microscopic view of commercially available graphene in copper membrane is shown in FIG.4A. The Raman spectroscopic analysis as shown in FIG. 4B shows the I_{2D}/I_G value as 1.8 which is greater than 1.5 indicating the presence of monolayer of graphene. The first chamber had salt water as electrolyte and the second chamber had fresh water. The power generation was done with membranes of varying dimensions. The output ionic current was measured and the output power was calculated as output power = ionic current × applied voltage. The power calculation was validated using analytical and continuum simulations of 2D Poisson- Nernst- Plank equations with Navier- Stokes equations.

[0034] Theoretically calculated power generation using a membrane of size 1 cm by 1cm width graphene on copper membrane:

[0035] A graphene in copper membrane of 1 cm length and 1 cm width with single 1 mm pore was taken same as the experimental set up. A single 1 mm pore was drilled in the graphene/copper membrane using femtosecond laser. The potassium concentration in the membrane is shown in FIG. 5A and potential distribution in FIG. 5B. The output power calculated is shown in Table. 1.

Table. 1: Output power using a membrane of size 1 cm × 1 cm

Parameters	**Value**
Thickness of the Graphene+Copper Membrane	18 μm
Diameter of the pore	1 mm
Surface charge density	0 mC/m2
Applied Voltage	0.4 V
Bulk concentration	0.6 M
Theoretical current (calculated)	0.16 (A)
Power = Current * Voltage	0.064 W or 64 mW

For a 1mm pore in a graphene/Copper membrane of 1cm × 1cm the calculated power is 64 mW which is very closely matching the experiments. The theoretical power vs pore area with a single pore is illustrated in FIG. 6A. The size of the single pore is varied from 0.2mm to 1mm. The power increases as the size of the pore increases. FIG. 6B and FIG. 6C illustrates the power with pore area for multiple pores drilled inside the 1cm×1cm membrane. The number of holes punched is 4 and 7 respectively, in FIG. 6B and FIG. 6C, respectively. FIG. 6D shows the individual theoretical potassium and Chlorine current and the total current with pore area for a single punched pore in a 1cm × 1cm graphene/copper membrane.

[0036] Example. 2: Experimental power generation in Osmotic power generation systems that uses graphene in copper membrane and varying electrolytes with 1 cm × 1cm graphene/copper membrane and single punched pore of 1mm to validate the theoretical calculations.

[0037] This experimental constructed Osmotic generator having a graphene/Cu membrane had a single pore of 1mm diameter. The thickness of graphene/copper is 18μm similar to theoretical calculations. The electrolytes were water or KCl solution of different concentrations. Each experiment was repeated for four times minimum to ensure repeatability of results. For an osmotic power generator using 0.6M in the left reservoir and 0.6mM KCl Solution in the right reservoir as electrolytes (same as theoretical predictions are considered) the output power is 48 mW as shown in Table. 2. Another set of experiment varying the concentration of left reservoir and right reservoir where left reservoir is 2M and right reservoir is 0.2mM KCl Solution the output power is 47mW as shown in Table. 3. Table. 4 and Table.5 shows the output power when the right reservoir is changed from low salinity concentration KCl to DI (Deionized water) to see the effect of water as a buffer solution. The electrolyte is distilled water and KCl solution for producing the power of 25 mW as tabulated in Table. 4. The results tabulated in Table. 5 were produced when the right reservoir is tap water or low saline water and left reservoir is KCl solution of 0.2mM concentration.

[0038] The experiments were matching with theoretical predictions where for a 1mm pore diameter in a 18 µm graphene/copper membrane where the graphene monolayer membrane thickness is 0.345 nm and the copper membrane thickness is 18 µm, the theoretical power calculated by analytically solving 2D Poisson+Nernst Planck and Navier-Stokes equations over this embodiment is 62 mW which is very close to the experiments of 45 mW to 55 mW for a 1 mm diameter pore. Also, the said analytical open circuit potential for a concentration gradient of 1000, with high concentration solution in reservoir 1 is 0.6 M and low salinity concentration in reservoir 2 is 0.6 mM calculated using the famous Nernst equation is 0.4 V which is fairly matching the experiments showin in Table 2, which is 0.37 V.

Table. 2: Output Power Using 0.6M and 0.6mM KCl Solutions

	Using 0.6M and 0.6mM KCl Solution		
	Max Voltage (mV)	Voltage (Stationary) (mV)	Power (Avg)
1	373	125	48mW
2	303	113	
3	435	145	

Table 3: Output Power Using 2M and 0.2mM KCl Solutions

	Using 2M and 0.2mM KCl Solutions		
	Max Voltage (mV)	Voltage (Stationary) (mV)	Power (Avg)
1	455	140	47mW
2	370	123	
3	310	121	
4	317	133	

Table. 4: Output Power Using DI Water and KCl solution

	Using DI water and 0.2mM KCl Solution		
	Max Voltage (mV)	Voltage (Stationary) (mV)	Power (Avg)
1	207	120	25mW

Table. 5: Output Power Using Tap Water and KCl Solution

	Using Tap water and 0.2mM KCl Solution

	Max Voltage (mV)	Voltage (Stationary) (mV)	Power (Avg)
1	83	39	32mW

[0039] Although the detailed description contains many specifics, these should not be construed as limiting the scope of the invention but merely as illustrating different examples and aspects of the invention. It should be appreciated that the scope of the invention includes other embodiments not discussed herein. Various other modifications, changes and variations which will be apparent, to those skilled in the art, may be made in the arrangement, operation and details of the system and method of the present invention disclosed herein without departing from the spirit and scope of the invention as described here. While the invention has been disclosed with reference to certain embodiments, it will be understood by those skilled in the art, that various changes may be made and equivalents may be substituted, without departing from the scope of the invention. In addition, many modifications may be made to adapt to a particular situation or material the teachings of the invention without departing from its scope.

WE CLAIM:

1. An osmotic power generator system (160) comprising:

a housing (101);

a porous scalable membrane (160) having a first surface and a second surface placed within the housing (101), the porous scalable membrane (160) comprising:

a first membrane (170) selected from SiNx (Silicon nitride) or Cu (Copper) membrane; and

a monolayer graphene membrane (180) mounted on a surface of the first membrane (170), wherein the first membrane and the monolayer graphene membrane (180) have one or more pores (182);

a first chamber (110) disposed on the first surface of the membrane and comprising a first electrode (130) and a first electrolyte (112);

a second chamber (120) disposed on the second surface of the membrane and comprising a second electrode (140) and a second electrolyte (122); and

a load connected between the first electrode (130) and the second electrode (140), wherein

the system is configured to pass ions between the first and second surfaces of the porous membrane due to an osmotic gradient between the first (112) and the second electrolytes (122) to generate a difference in potential and an ionic current between the first (130) and second electrodes (140).

2. The system as claimed as in claim 1, wherein a size of the pore in the monolayer membrane is in a range of 0.5mm to 2mm.

3. The system as claimed as in claim 1, wherein a pore density is in a range of 4 to 7 pores in the scalable membrane of dimension 1cmx1cm.

4. The system as claimed as in claim 1, wherein a thickness of the scalable membrane (160) is in a range 16 to 20 µm.

5. The system as claimed as in claim 1, wherein a thickness of the monolayer membrane (180) is in a range 0.342 to 0.345 nm.

6. The system as claimed as in claim 1, wherein the first electrolyte (112) is salt water or sea water.

7. The system as claimed as in claim 1, wherein the second electrolyte (122) is fresh water or river water or saline water of predetermined concentration.

8. The system as claimed as in claim 1, wherein the power generated is in the range of 58 to 70 mW/mm^2.

9. The system as claimed as in claim 1, wherein the pore area / a membrane area is in the range 0.025 to 0.88.

OSMOTIC POWER GENERATION SYSTEM

ABSTRACT OF THE DISCLOSURE

The invention discloses an osmotic power generation system (100). The osmotic power generation system (100) incorporates a scalable porous membrane (160) that partitions the housing into a first chamber (110) and a second chamber (120). The first chamber has a first electrolyte (112) and an electrode (130) and the second chamber (120) has a second electrolyte (122) and an electrode (140). The system (100) is capable of generating power when the membrane (160) is kept in a concentration gradient. The scalable porous membrane (160) includes a first Cu membrane (170) a monolayer graphene membrane (180) mounted on the first membrane (170). The osmotic power generator system is configured to generate 58 to 70 mW/mm^2 and thus produce megawatts power in relatively small membrane area. The system (100) is used for energy harvesting, energy storage and in energy conversion devices like fuel-cell, water battery and power generator.

(FIG. 1)