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Krupenkin

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(54) **METHOD AND APPARATUS FOR ENERGY HARVESTING USING MICROFLUIDICS**

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(22) Filed: **Aug. 22, 2007**

(51) **Int. Cl.**
F02B 63/04 (2006.01)
H02K 33/00 (2006.01)
H01L 41/00 (2006.01)

(52) **U.S. Cl.** .... **290/1 R**; 310/36; 310/339

(58) **Field of Classification Search** .... 290/1 R; 310/339, 328, 800, 36, 309; 438/48, 51; 320/166, 101; 422/186.2; 322/2 A
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,567,373 A 9/1951 Giacoletto
3,008,334 A * 11/1961 Lees 73/503
3,013,201 A 12/1961 Goldie
3,094,653 A 6/1963 May
3,405,334 A 12/1968 Jewett
3,610,970 A * 10/1971 Skinner 310/10
4,054,826 A 10/1977 Wahlstrom
4,126,822 A 11/1978 Wahlstrom
4,127,804 A 11/1978 Breaux
4,595,852 A 6/1986 Gundlach
4,814,657 A 3/1989 Yano
4,897,592 A 1/1990 Hyde
5,541,465 A * 7/1996 Higuchi et al. 310/309
6,127,812 A 10/2000 Ghezzo
6,255,758 B1 7/2001 Cabuz
6,424,079 B1 * 7/2002 Carroll 310/339
6,545,815 B2 4/2003 Kroupenkine
6,750,590 B2 6/2004 Potter
6,936,994 B1 8/2005 Gimlan
7,112,911 B2 9/2006 Tanaka
7,446,450 B2 * 11/2008 Boland et al. 310/309
2011/0001493 * 1/2011 Lohndorf et al. 324/660

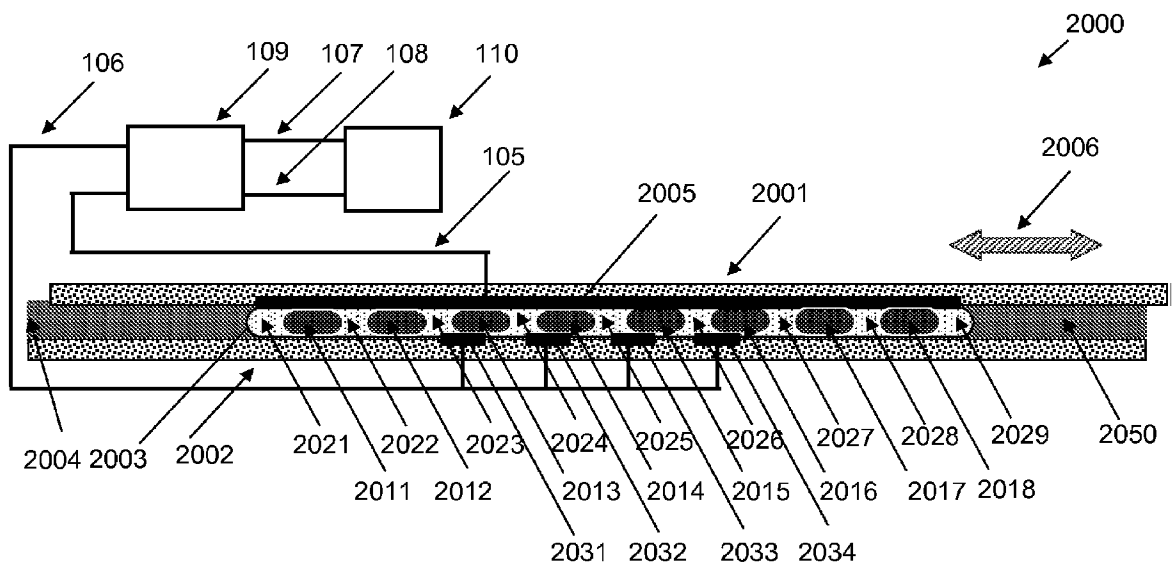
* cited by examiner

Primary Examiner—Julio Gonzalez

(57) **ABSTRACT**

An apparatus comprising a mechanical-to-electrical energy converting device having a plurality of electrodes and a fluidic body which comprises spatially separated conductive and dielectric liquid regions. Said fluidic body is configured to reversibly move as a whole with respect to said plurality of electrodes under the influence of a mechanical force. Each cycle of said reversible motion of said fluidic body causes multiple alternations of the amount of electrical charge accumulated by the electrodes, whereby generating electrical current flow between said electrodes.

34 Claims, 11 Drawing Sheets



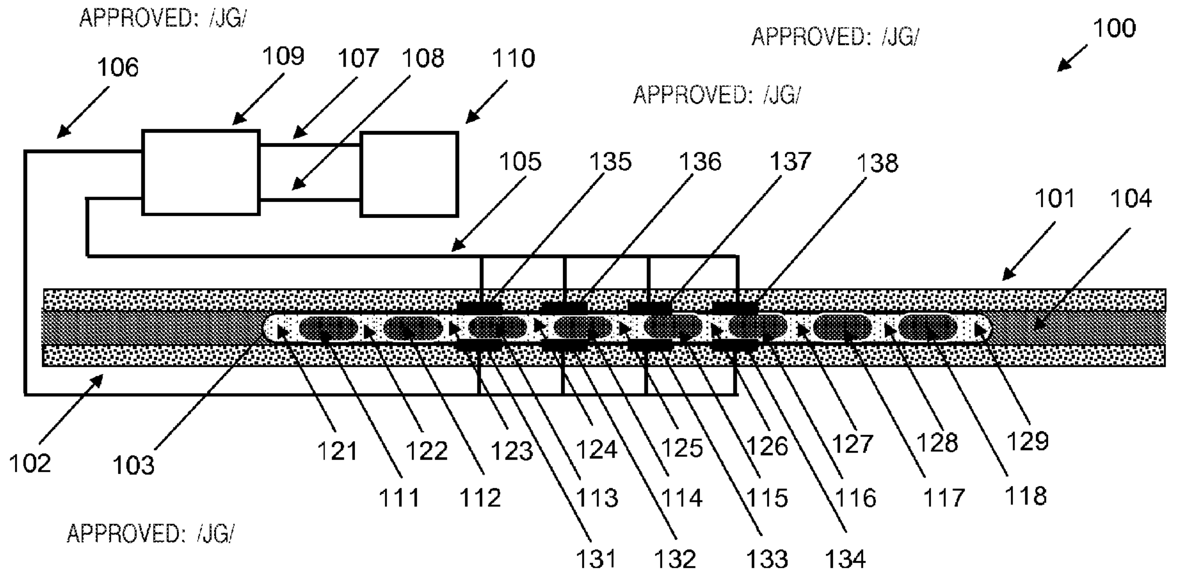


FIGURE 1

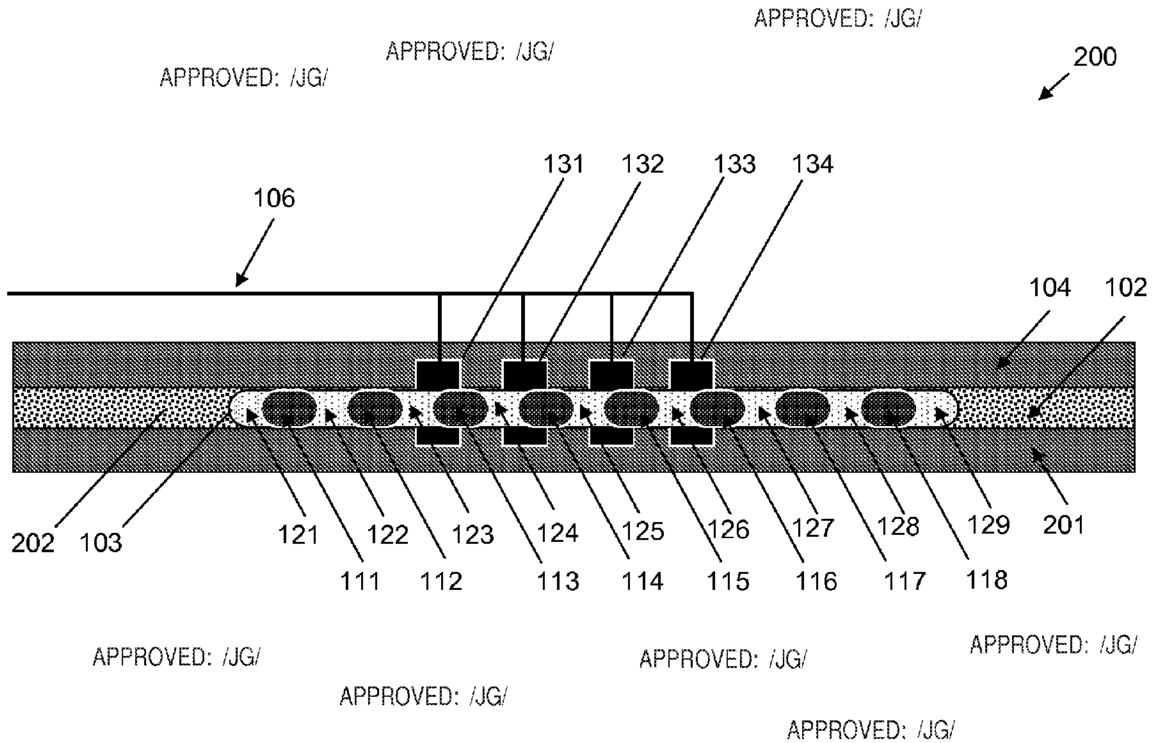


FIGURE 2

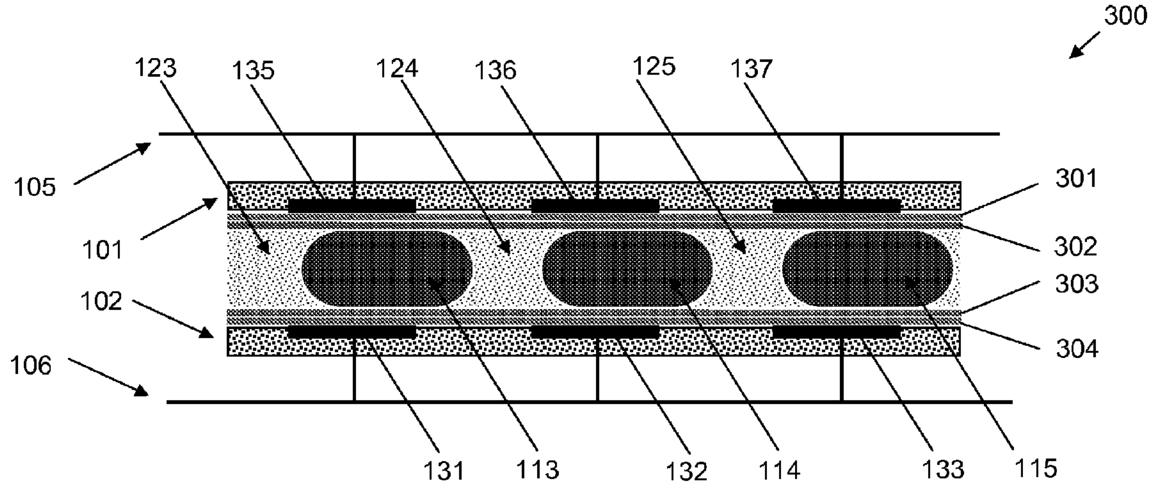
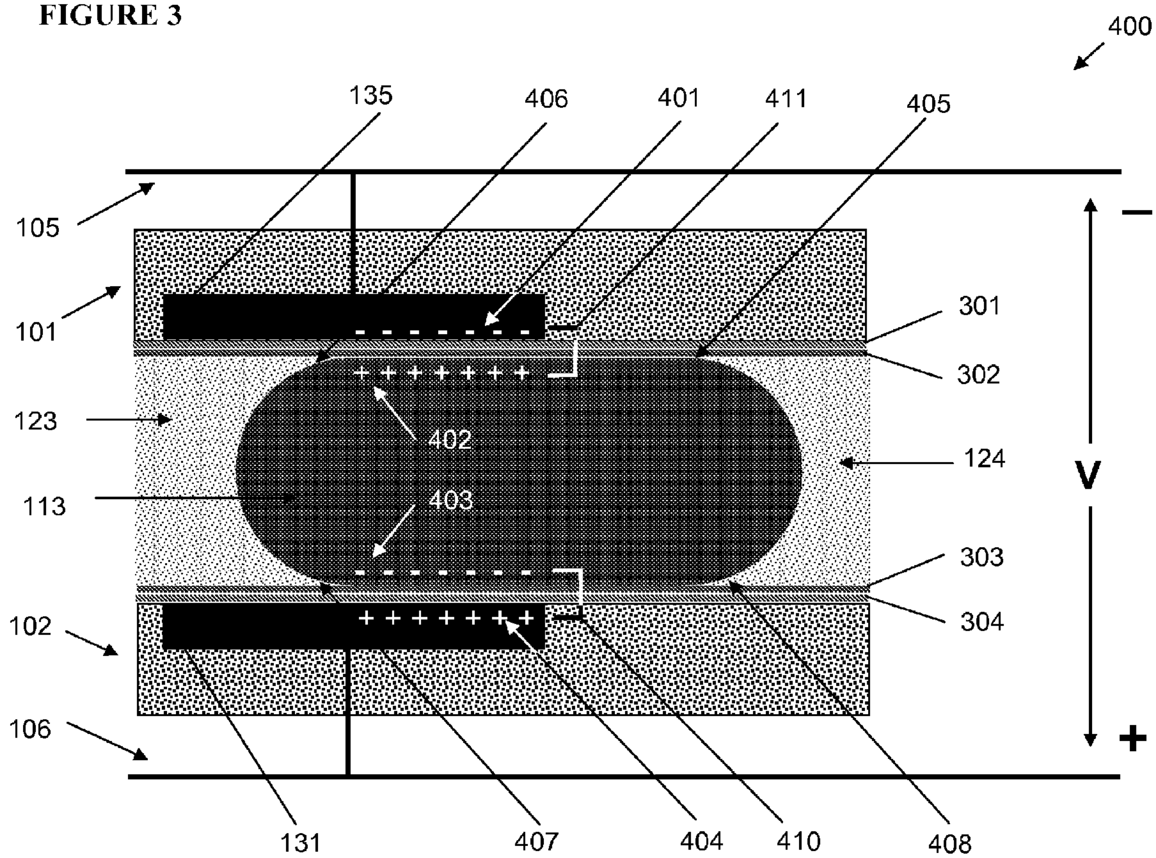


FIGURE 3



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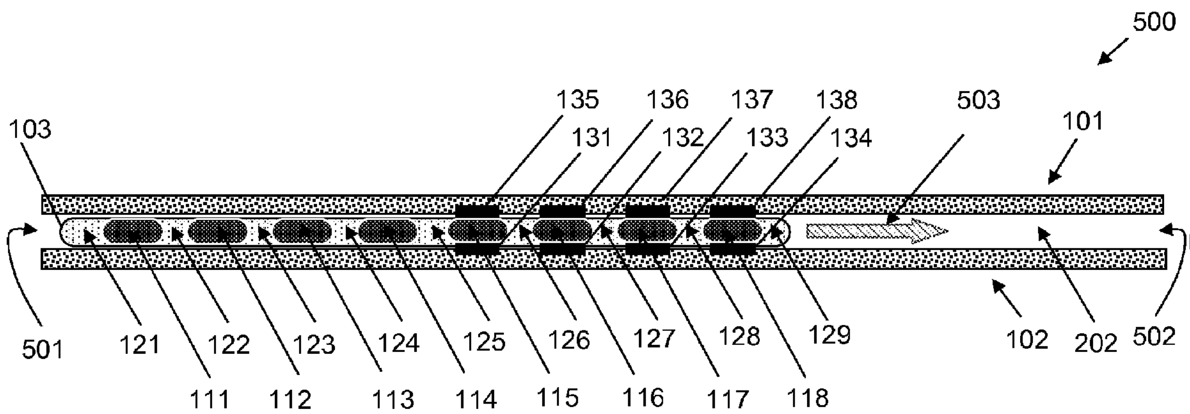

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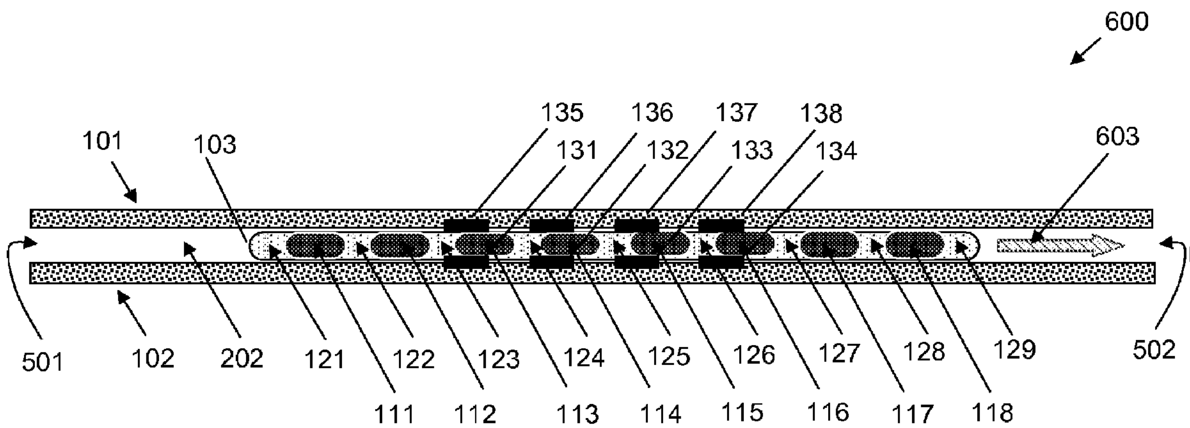
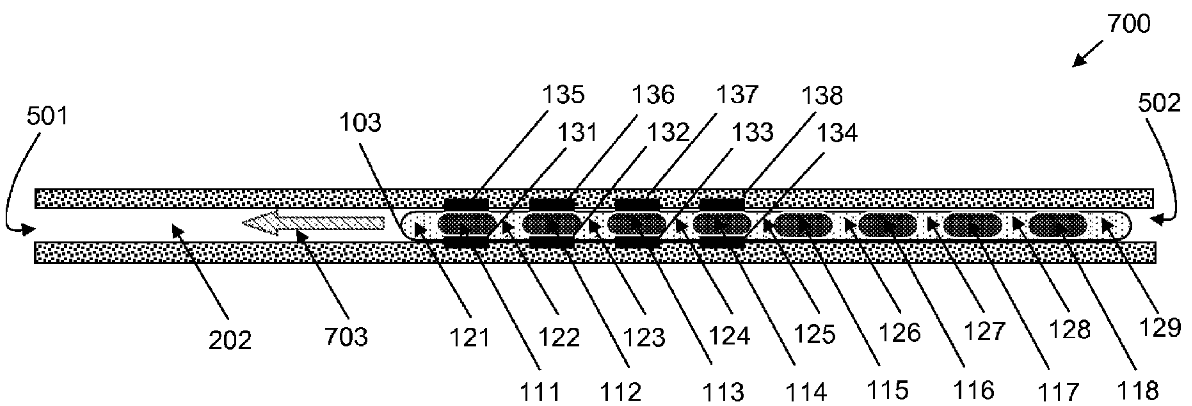


FIGURE 6



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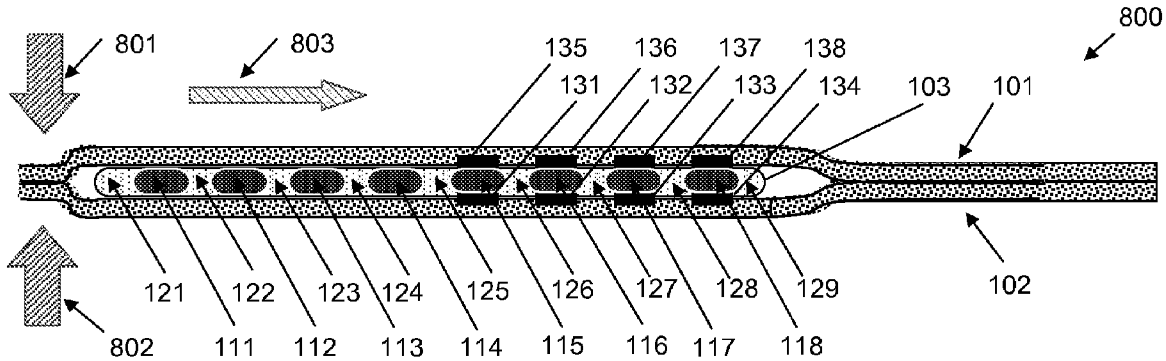

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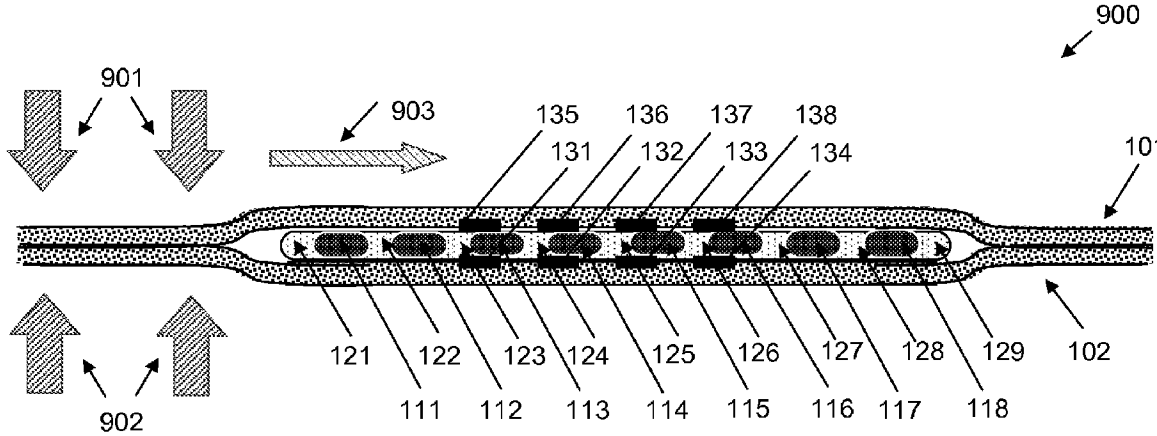


FIGURE 9

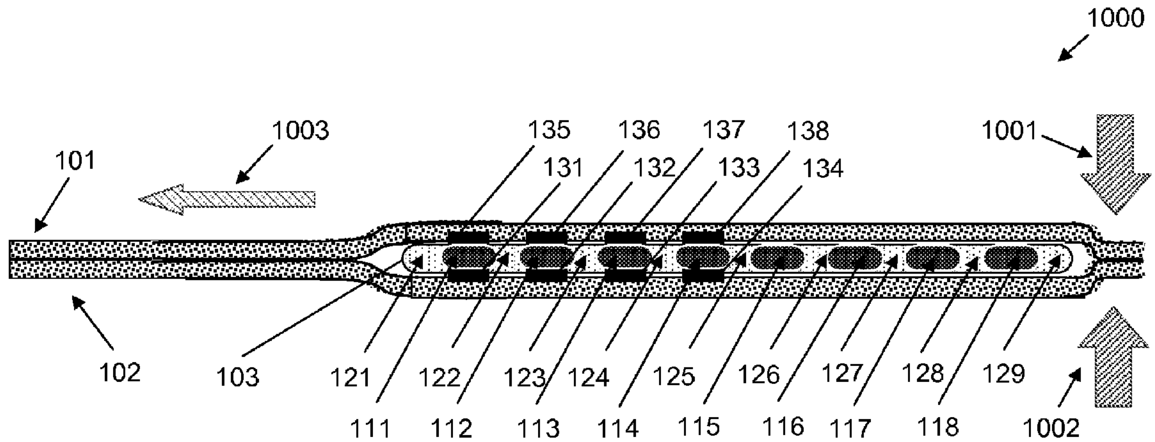
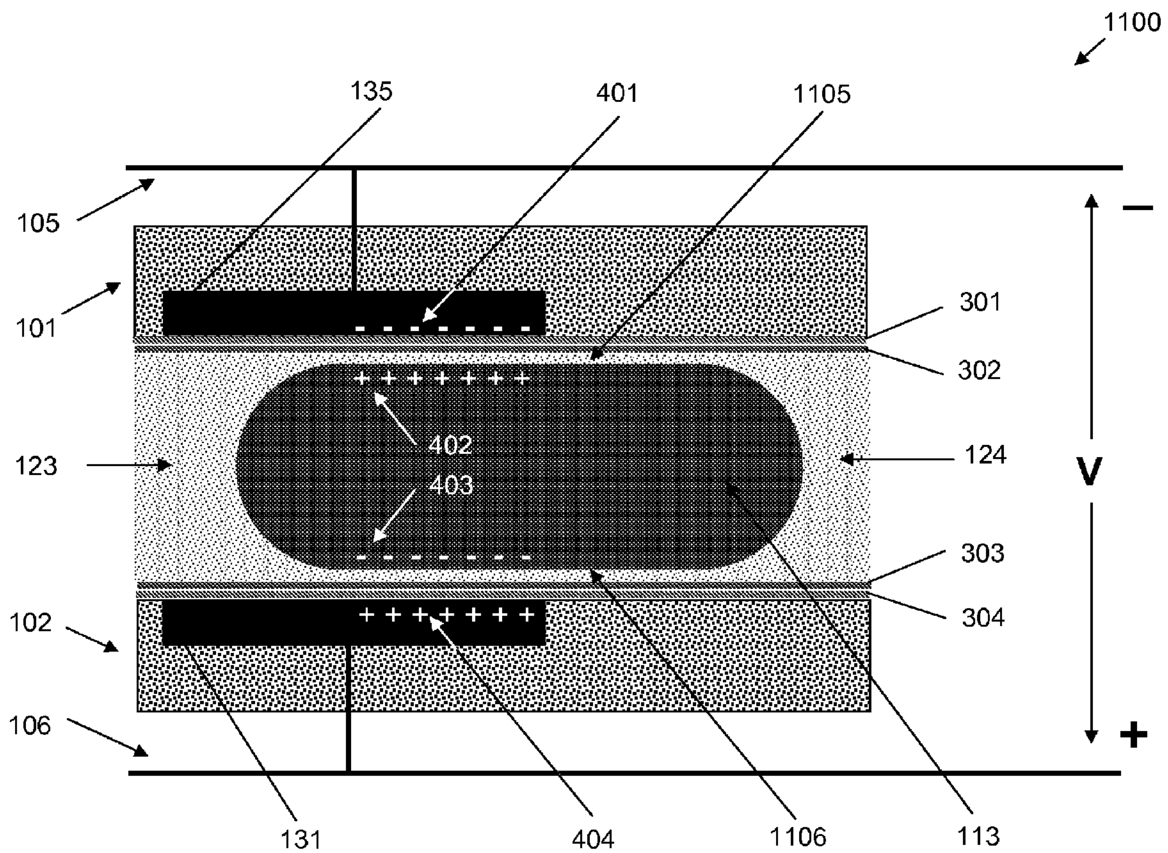


FIGURE 10



1100
135
401
1105
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FIGURE 11

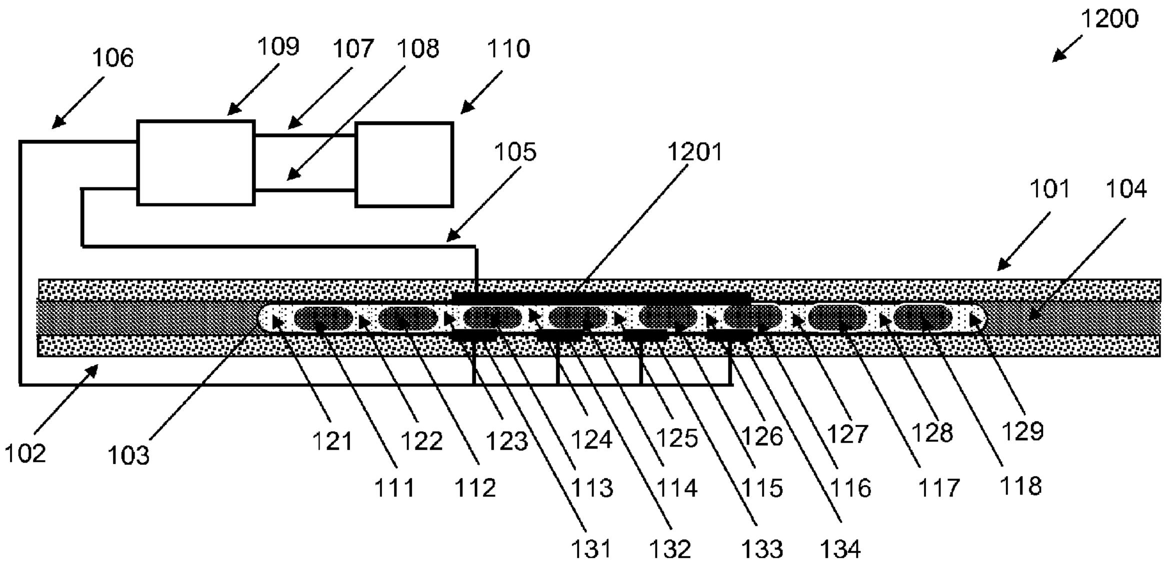

FIGURE 12

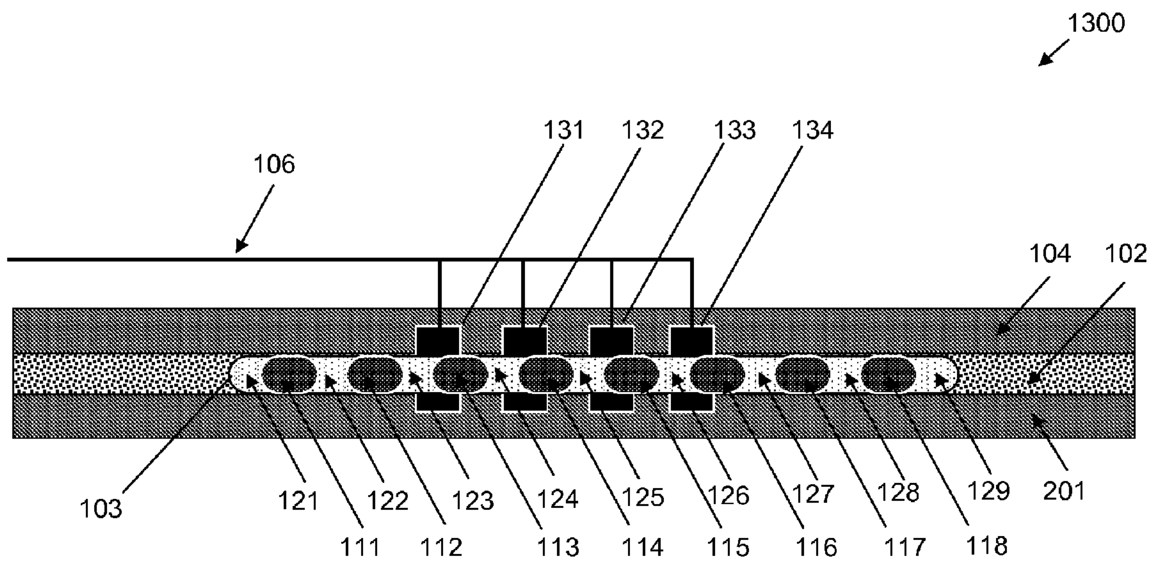

FIGURE 13

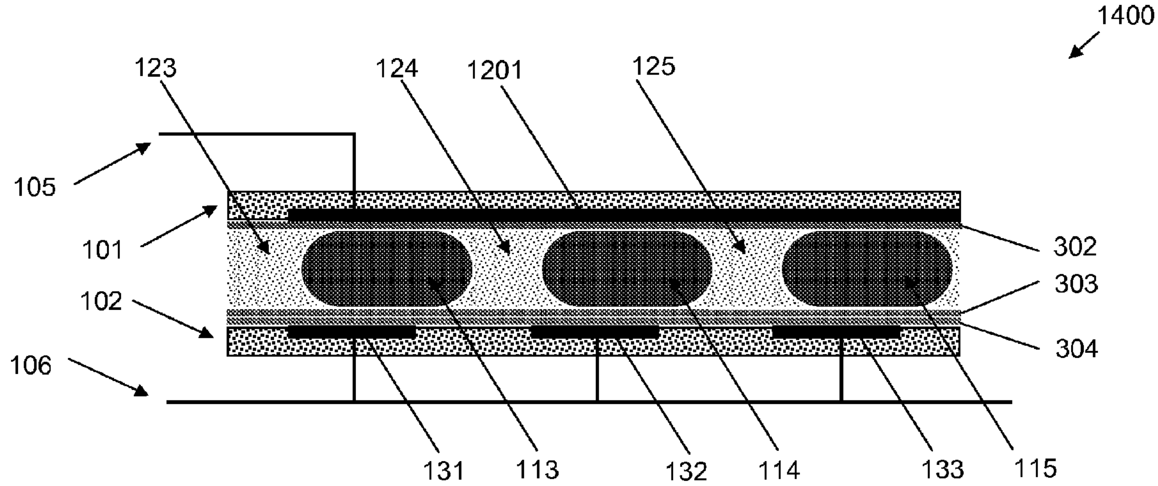

FIGURE 14

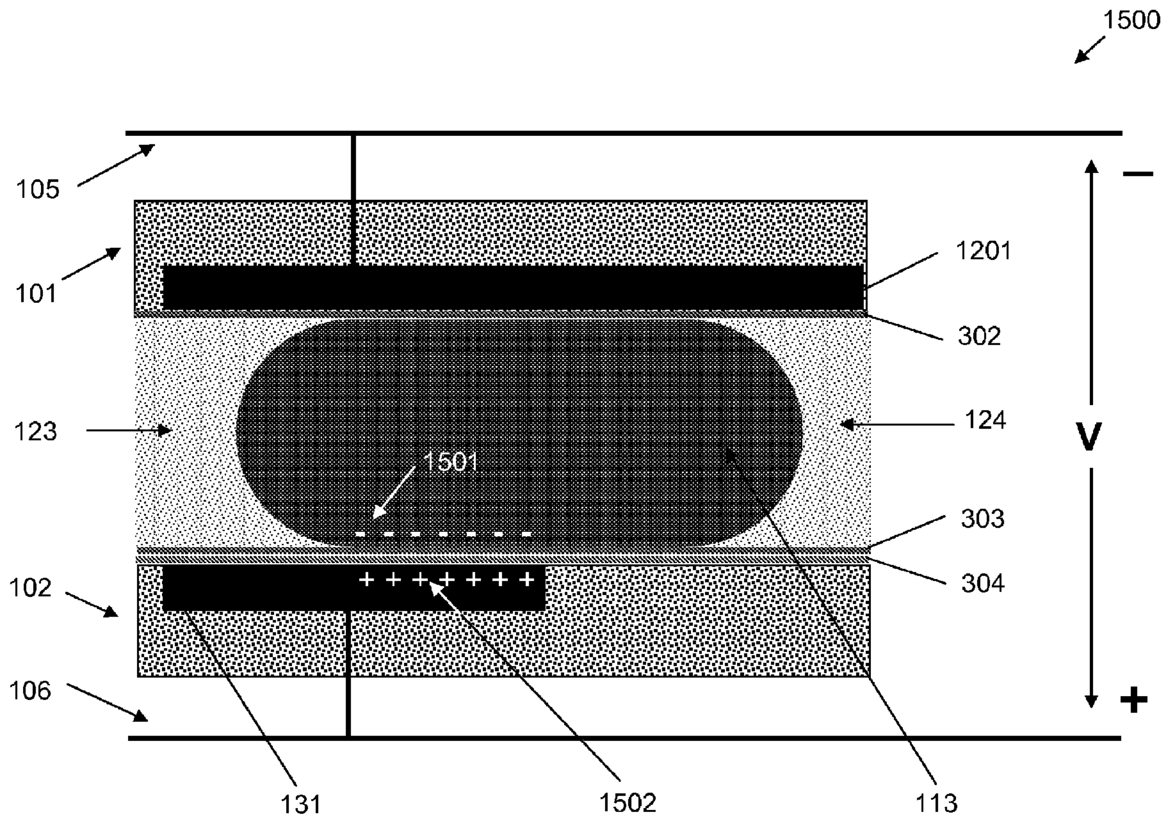

FIGURE 15

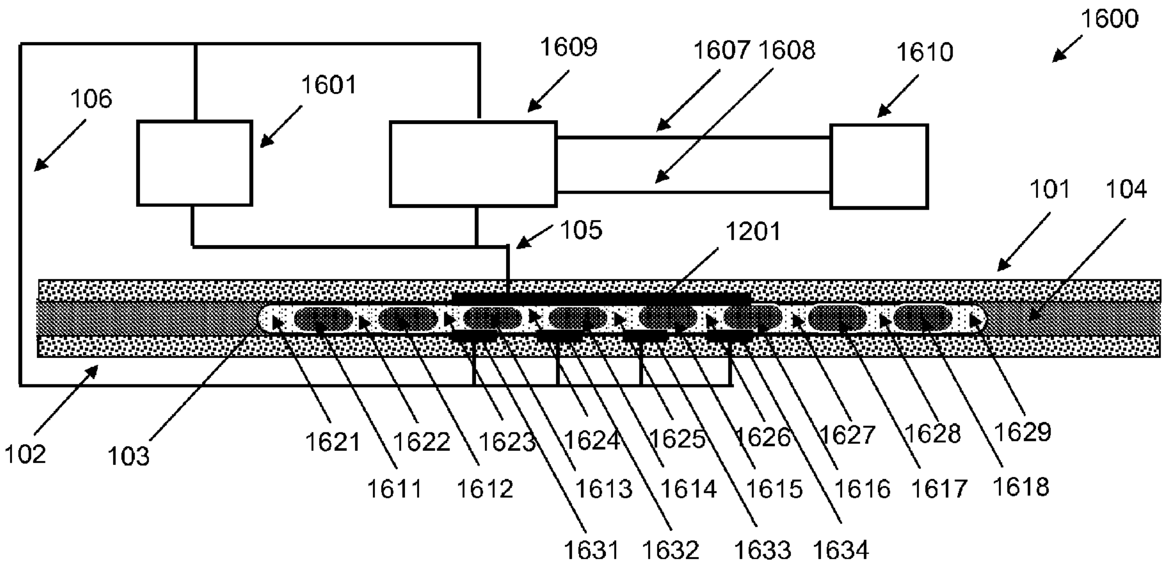

FIGURE 16

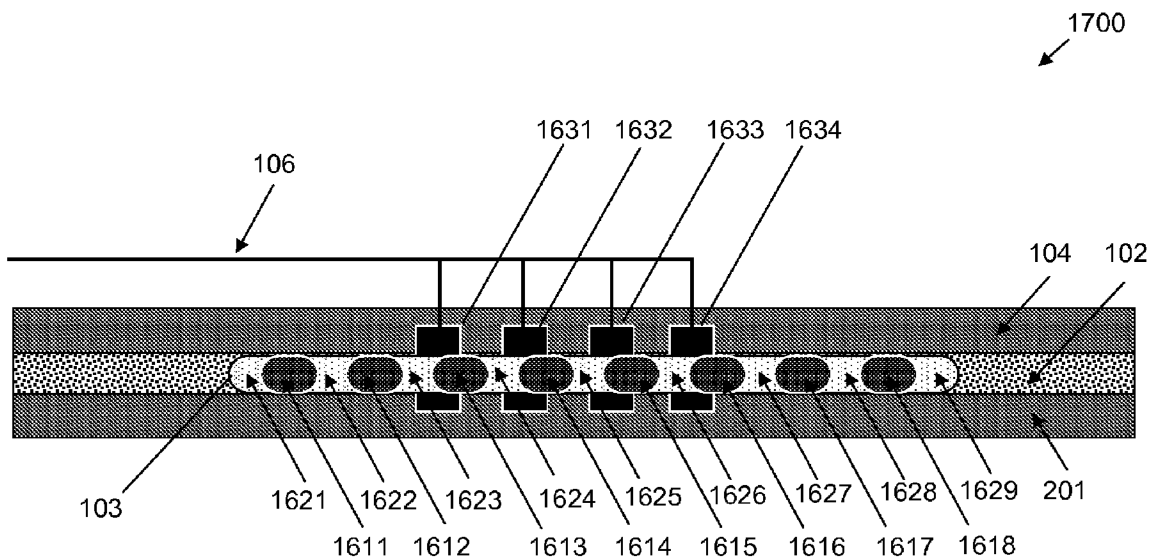

FIGURE 17

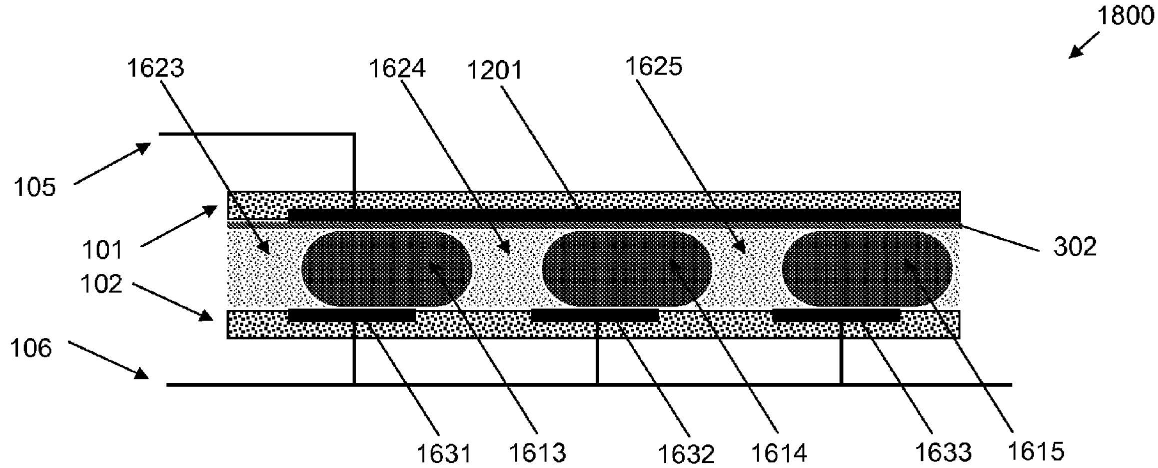

FIGURE 18

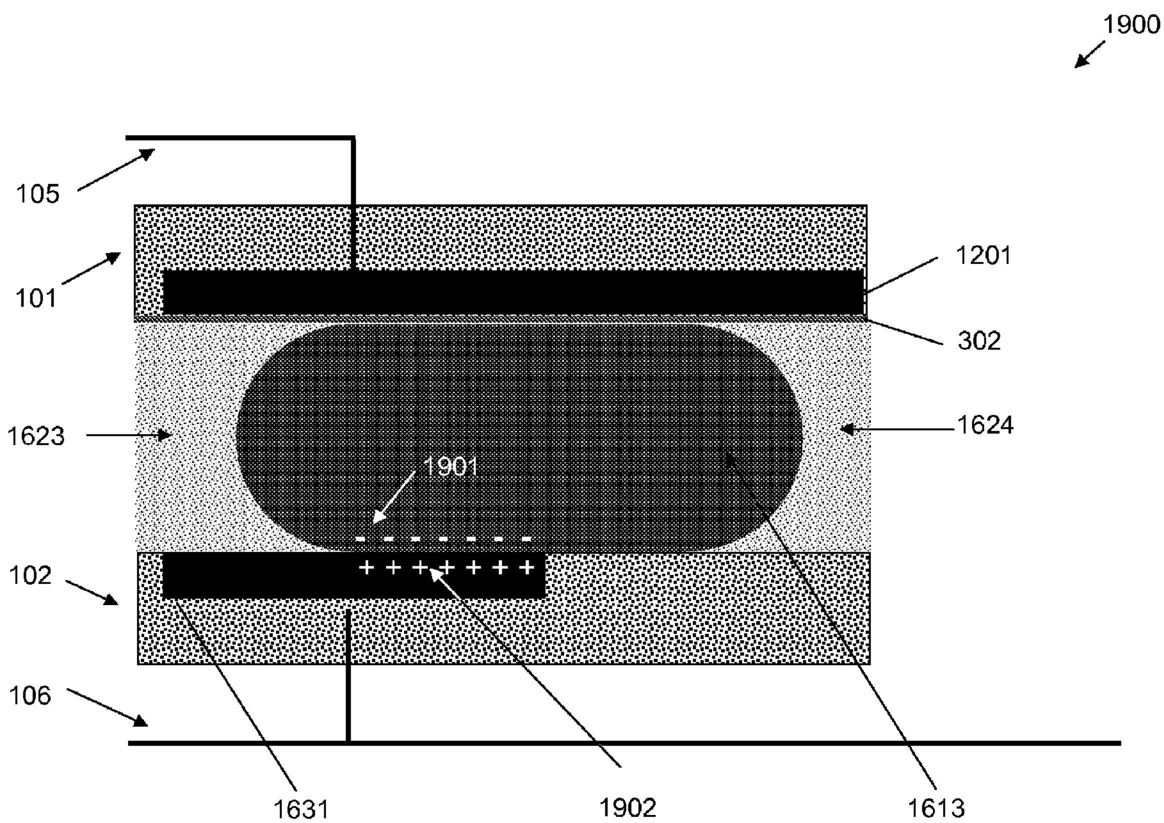

FIGURE 19

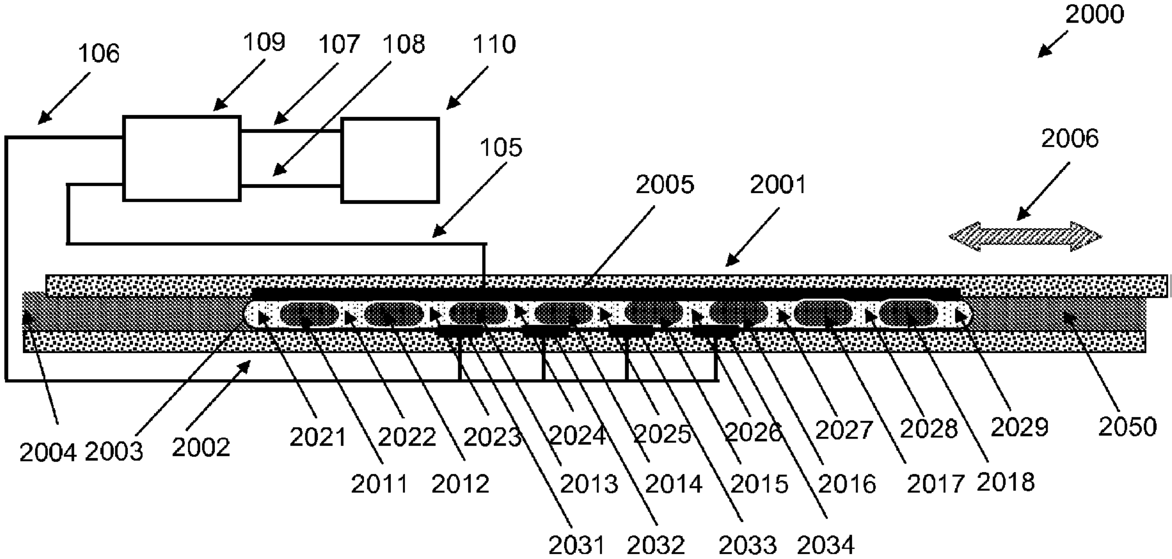

FIGURE 20

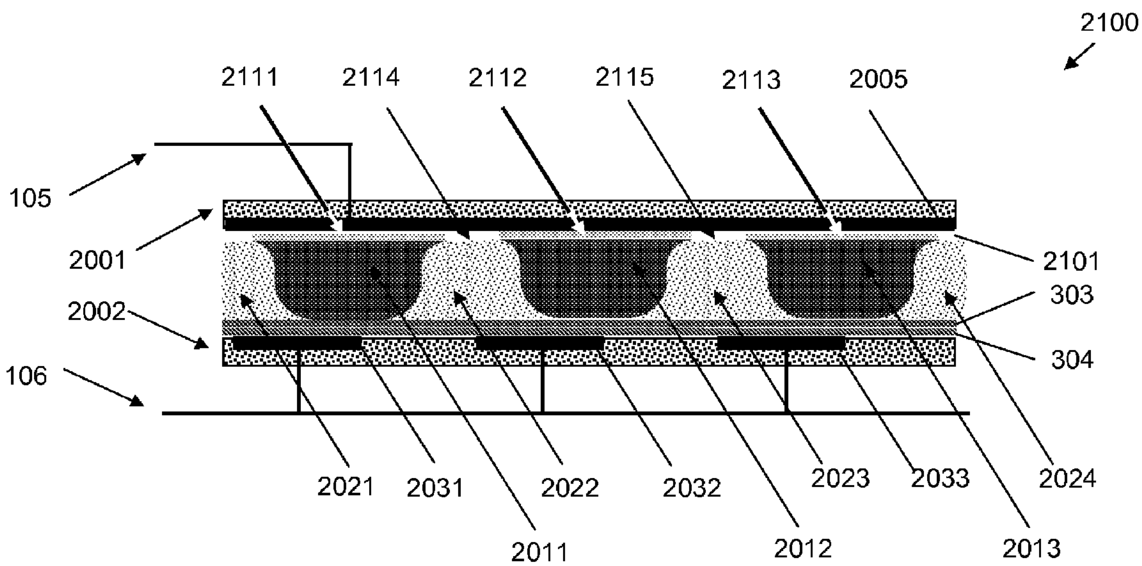

FIGURE 21

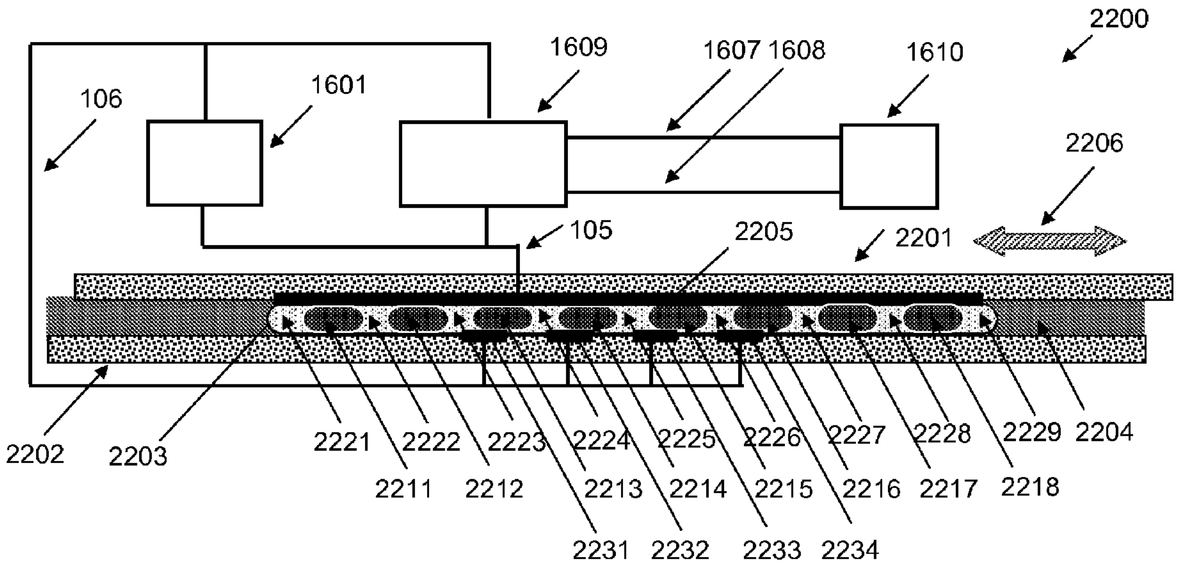

FIGURE 22

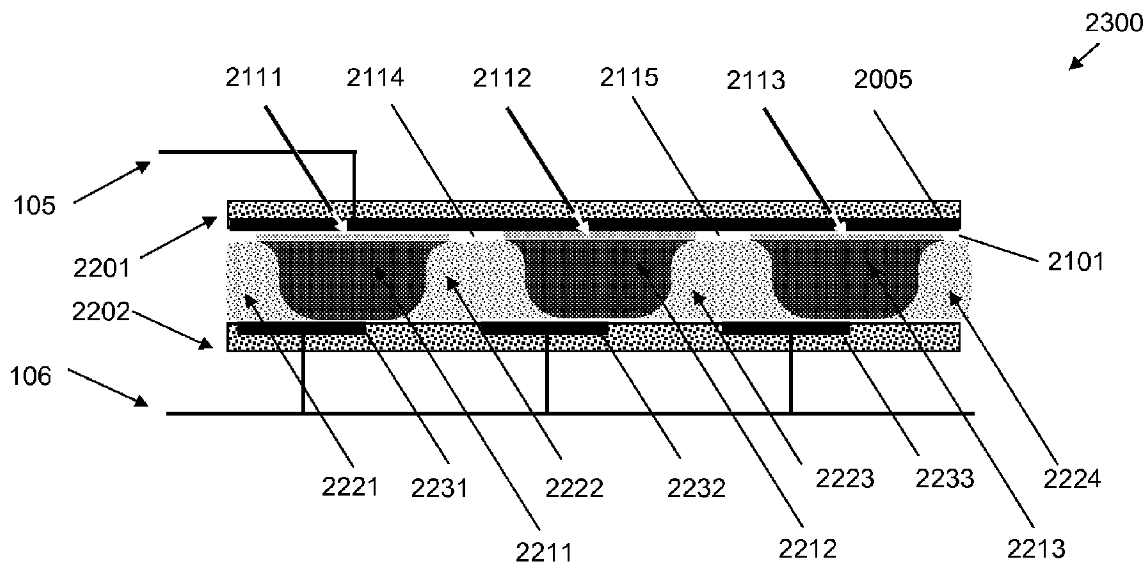

FIGURE 23

METHOD AND APPARATUS FOR ENERGY HARVESTING USING MICROFLUIDICS

TECHNICAL FIELD OF THE INVENTION

The present invention is directed, in general, to a device for harvesting mechanical energy and converting it into electrical energy, and methods for using and manufacturing such a device.

BACKGROUND OF THE INVENTION

A growing need to produce portable and wireless electronics with extended lifespans put constantly increasing strain on available power sources for such systems. Current mobile devices usually must be designed to include electrochemical batteries as the power source. The use of batteries can be often troublesome due to their limited capacity and lifespan, thus necessitating their periodic recharging or replacement.

One of the technologies that holds a promise to substantially alleviate current reliance on the electrochemical batteries is energy harvesting. Energy harvesting devices are designed to capture the ambient energy surrounding the electronics and convert it into usable electrical energy. The concept of energy harvesting works towards developing self-powered devices that do not require replaceable power supplies.

Many types of energy harvesters exist, each offering differing degrees of usefulness depending on the application. Perhaps the best-known energy harvesters are solar cells, which have long been used to power simple hardware components such as calculators or emergency telephones.

Another type of harvesters converts the energy contained in a vibrating object into electrical energy. These systems have been demonstrated to extract energy from floors, stairs, and equipment housings.

A third type of harvesters uses mechanical energy, such as that produced by a person walking and an object's movement. For example, some electronic watches, currently commercially available, operate by converting mechanical energy available from the swing of a person's arm to useful electrical power.

Currently the power output of energy harvesters is substantially limited by the efficiency of the energy converting transducers and the raw energy available, remaining in the microwatt to milliwatt range. However, recently, with the advent of mobile computing, the demand for more powerful energy harvesting devices with the output on the order of watts or even tens of watts has substantially increased.

In that respect, harvesters that convert mechanical energy into electrical energy are particularly promising as they can tap into high power sources such as human motion. For instance, from resting to a fast sprint, the human body expends roughly 0.1 to 1.5 kilowatt. Only part of this energy is available for harvesting, but even a modest part of this vast energy pool can constitute a substantial power source.

For instance, one of the promising ways to extract energy from people's motion is by tapping their gait. Humans typically exert up to 130 percent of their weight across their shoes at heel strike and toe-off, and standard jogging sneakers cushioned soles can compress by up to a centimeter during a normal walk. For a 154-pound person, this indicates that about 7 Watt of power could be available per foot at a 1-Hertz stride from heel strike alone. For comparison, such relatively power-hungry mobile electronic devices as mobile phones and laptops typically consume power on the order of 1 Watt and 15 Watt respectively.

Successful high-power mechanical energy harvesting requires an efficient transduction mechanism to generate electrical energy from environmental mechanical motion. One of the key requirements is to maximize the coupling between the mechanical energy source and the transduction mechanism. This is a complicated problem due to often unpredictable aperiodic nature of environmental mechanical motion and a very broad range of forces, displacements and accelerations, exhibited by this motion.

Currently there are three major types of mechanical-to-electrical energy converting devices, or transducers as they are sometimes called, namely piezoelectric, electromagnetic, and electrostatic. Each of them has their respective advantages and shortcomings, but none of them can currently provide a high-power-output solution capable of effectively coupling to a broad range of environmental mechanical motion.

In particular, piezoelectric transducers are inexpensive, lightweight, compact, have no moving parts, and can be easily incorporated in a broad range of devices. However, they require high-stress, low-displacement mechanical motion, generate high-voltage, low-current output, and have low conversion efficiency.

To the contrary, electromagnetic systems are best adapted to high-displacement, low-force mechanical motion. Their conversion efficiency can be high and the output voltage can be tuned to a broad range of values. Unfortunately, due to a high-displacement requirement they typically need additional complicated mechanical or hydraulic mechanisms to achieve effective coupling with the common types of environmental mechanical motion. This often makes such systems prohibitively bulky and expensive.

Electrostatic systems are typically inexpensive, lightweight, have high conversion efficiency and potentially a broad range of tunablty in terms of allowable mechanical force and displacement. However, in currently employed systems high values of electrical field are typically required to achieve even modest levels of output power. These high values of electrical field translate into high operational and output voltages, making these electrostatic devices impractical in many applications.

Thus, there is clearly a need for a simple, compact, and efficient high-power mechanical-to-electrical energy converting device capable of combining a wide range of possible output voltages with the ability to effectively couple to environmental motion with a broad range of mechanical displacements and forces.

SUMMARY OF THE INVENTION

To address one or more of the above-discussed needs, one embodiment of the present invention is an apparatus. The apparatus comprises a mechanical-to-electrical energy-converting device. The energy-converting device comprises a plurality of electrodes and a fluidic body. Said fluidic body comprises spatially separated regions of at least one conductive and at least one dielectric liquid arranged in a predetermined alternating pattern. Said fluidic body is configured to reversibly move as a whole with respect to said plurality of electrodes under the influence of a mechanical force. Each cycle of said reversible motion of said fluidic body causes multiple alternations of the amount of electrical charge accumulated by the electrodes, whereby generating electrical current flow between said electrodes.

Another embodiment is a method that comprises generation of electrical energy from mechanical energy. Generation of electrical energy comprises reversibly moving a fluidic body comprising alternating conductive and dielectric liquid regions against electrostatic force generated by a plurality of electrically charged electrodes. Each cycle of said reversible motion causing multiple alternations of the amount of electrical charge accumulated by the electrodes, thus generating electrical current flow between said electrodes.

Still another embodiment is a method that comprises manufacturing a mechanical-to-electrical energy-converting device. One or more electrodes are disposed over at least one substrate. A fluidic body comprising a plurality of alternating conductive and dielectric liquid regions is formed and disposed in close proximity to said electrodes. Said electrodes are coupled to a circuit means for transferring electrical current generated by said energy-converting device to power consumption means.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is best understood from the following detailed description, when read with the accompanying figures. Various features may not be drawn to scale and may be arbitrarily increased or reduced in size for clarity of discussion. Reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

FIG. **1** presents a cross-sectional view of a first exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **2** presents a plan view of a part of the first exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **3** presents a close-up cross-sectional view of a part of the first exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **4** presents a close-up cross-sectional view of another part of the first exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **5** presents a cross-sectional view of a part of the first exemplary embodiment of an apparatus for converting mechanical energy into electrical energy at the beginning of the reversible motion cycle;

FIG. **6** presents a cross-sectional view of a part of the first exemplary embodiment of an apparatus for converting mechanical energy into electrical energy at the intermediate state of the reversible motion cycle;

FIG. **7** presents a cross-sectional view of a part of the first exemplary embodiment of an apparatus for converting mechanical energy into electrical energy at the end of the reversible motion cycle;

FIG. **8** presents a cross-sectional view of a part of a second exemplary embodiment of an apparatus for converting mechanical energy into electrical energy at the beginning of the reversible motion cycle;

FIG. **9** presents a cross-sectional view of a part of the second exemplary embodiment of an apparatus for converting mechanical energy into electrical energy at the intermediate state of the reversible motion cycle;

FIG. **10** presents a cross-sectional view of a part of the second exemplary embodiment of an apparatus for converting mechanical energy into electrical energy at the end of the reversible motion cycle;

FIG. **11** presents a close-up cross-sectional view of a part of a third exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **12** presents a cross-sectional view of a forth exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **13** presents a plan view of a part of the forth exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **14** presents a close-up cross-sectional view of a part of the forth exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **15** presents a close-up cross-sectional view of another part of the forth exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **16** presents a cross-sectional view of a fifth exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **17** presents a plan view of a part of the fifth exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **18** presents a close-up cross-sectional view of a part of the fifth exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **19** presents a close-up cross-sectional view of another part of the fifth exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **20** presents a cross-sectional view of a sixth exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **21** presents a close-up cross-sectional view of a part of the sixth exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **22** presents a cross-sectional view of a seventh exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

FIG. **23** presents a close-up cross-sectional view of a part of the seventh exemplary embodiment of an apparatus for converting mechanical energy into electrical energy;

DETAILED DESCRIPTION

Present invention benefits from realization that electrostatic mechanism of converting mechanical energy into electrical energy can be greatly improved by combining it with modern microfluidics technology. A common approach to electrostatic energy conversion (e.g. disclosed in U.S. Pat. Nos. 6,936,994, 4,127,804, 6,127,812, 3,094,653, 3,013,201, 4,054,826, 6,750,590, 4,897,592, 4,126,822, 2,567,373, 3,405,334, 6,255,758, 7,112,911, 4,595,852, 4,814,657) consists of electrically charging one or more electrodes arranged in such a way as to create a strong electrical field in one or more regions in space and then reversibly moving a conductive or dielectric body against the force exerted by this field, thus causing electrical field variations in time. Since the amount of charge on the electrodes and the field strength are intimately related, electrical field variations cause charge variations, which, in turn, can be converted into useful electrical current. Charging of the electrodes can be accomplished either by external voltage source, such as electrochemical battery (e.g. as disclosed in U.S. Pat. Nos. 4,054,826, 6,936, 994), or through some internal process, such as tribo-electricity (e.g. as disclosed in U.S. Pat. No. 4,126,822), or, as proposed in one embodiment of the current invention, by spontaneous formation of electrical double-layer, similar to so called electrochemical supercapacitors.

The maximum electrical energy output that can be produced by the described energy conversion mechanism is directly proportional to the variation of the electrostatic field energy during the reversible motion of the mentioned above conductive or dielectric body. For a special case where each cycle of the reversible motion of the body causes multiple alternations of the electrostatic field energy from zero to some maximum value E_0, the total useful electrical energy E produced will be proportional to N E_0, where N is a number of electrostatic energy alternations per one cycle of reversible motion. For the simplest case of a set of electrodes having total capacity C and being maintained at a given electrical voltage differential V, electrostatic field energy E_0 is expressed as $E_0=0.5\ C\ V^2$. Here E_0 is energy measured in Joules [J], V is voltage measured in Volts [V], and C is capacitance measured in Farads [F].

Thus one can conclude that the maximum useful electrical power output of the conversion device can be achieved by maximizing capacity C, applied voltage V, or number of energy alternations N. Theoretically, increasing the value of applied voltage V would be a very effective strategy as the energy E_0 depends on the square of V. Unfortunately, high voltages are often undesirable and can substantially restrict the range of applications of the energy-conversion technology, especially when it comes to harvesting energy from such sources as human body motion. Fortunately, the remaining two parameters: capacity C and number of energy alternations N can be increased without such adverse effects.

For two electrodes that are substantially planar and are separated by distance d that is much smaller than their size the value of capacitance C can be expressed as $C=\epsilon_0\epsilon\ A/d$, where A is the area where electrodes overlap, measured in square meters [m^2], d is the distance between electrodes, measured in meters [m], ϵ is dimensionless permittivity of the media between electrodes, and $\epsilon_0=8.854\ 10^{-12}$ Farad/meter [F/m] is vacuum permittivity. Thus, the value of capacitance C can be increased either by increasing electrode area A or by decreasing distance between electrodes d. Adding more electrode area might be problematic in many applications as this would increase the size and weight of the device, but decreasing the distance d in many situations can be readily accomplished.

The following numerical example can further elucidate the above mentioned arguments. Lets us consider the energy-converting device with the electrode size consistent with the human footprint, for instance 5 cm by 7 cm, i.e. electrode area $A=35\ cm^2$. Assuming a readily achievable by modern micro-fabrication techniques distance between electrodes d=20 nanometers [nm] and permittivity of the media between electrodes $\epsilon=25$ (tantalum oxide) we obtain capacitance $C=39\ 10^{-6}$ F, or 39 microFarad [μF]. Thus, for applied voltage V=10 V electrostatic energy $E_0=2\ 10^{-3}$ J. This demonstrates that about 500 energy alternations per one cycle of environmental motion with 1 Hertz [Hz] frequency (e.g. human gait) are required in order to achieve theoretical power output on the order of 1 Watt, sufficient for operating such load as a mobile telephone.

Clearly, designing and fabricating a device that would satisfy the above-mentioned requirements using traditional mechanical engineering approach is extremely challenging. Not only some sort of a mechanical transducer capable of converting one cycle of environmental motion into about 500 mechanical oscillations is required, but the very requirement of preserving a 20 nm thick dielectric layer separating moving electrodes would introduce a whole gamut of reliability problems.

This is where modern microfluidics technology provides a crucial advantage. Microfluidics is a brunch of micro-fabrication which is concerned with developing means of handling small volumes of liquids. The main idea of the present invention is to employ fluidic structures potentially consisting of hundreds or even thousands of surface-tension-controlled microscopic volumes of liquids (e.g. volumes from picoliters to microliters) as movable elements in a mechanical-to-electrical energy converting device.

The invention is best understood by considering specific preferred embodiments. One embodiment of the present invention is an apparatus. FIG. **1** presents cross-sectional view of a first exemplary embodiment of an apparatus **100** for converting mechanical energy into electrical energy. FIG. **2** presents a plan view of a part **200** of the same apparatus, where parts **101**, **105**, **107**, **108**, **109**, **110**, **135**, **136**, **137**, **138** of apparatus **100** are removed and spacers **104** and **201** are rendered semitransparent for the clarity of presentation. For simplicity, FIG. **1** and FIG. **2** present electrical connectors only schematically, not reflecting their actual physical arrangement.

The apparatus **100** comprises two substrates **101** and **102** disposed substantially co-planar and separated by spacers **104** and **201**. Spacers **104** and **201** are disposed in such a way as to form a channel **202**. A plurality of electrodes **135**, **136**, **137**, **138** is disposed on substrate **101** and a plurality of electrodes **131**, **132**, **133**, **134** is disposed on substrate **102**. Substrates **101** and **102** and spacers **104** and **201** can be made of any solid dielectric material such as glass, textolite, or a solid plastic, including polycarbonate, polypropylene, or polytetrafluoroethylene. The electrodes **131**, **132**, **133**, **134**, **135**, **136**, **137**, **138** can be made of any solid conductive material, such as gold or tantalum, or indium tin oxide glass. In some preferred embodiments electrodes **131**, **132**, **133**, **134**, **135**, **136**, **137**, **138** comprise a tantalum film or a gold film.

A movable fluidic body **103** is disposed in channel **202** and configured to slide along channel **202** past electrodes **131**, **132**, **133**, **134**, **135**, **136**, **137**, **138**. Fluidic body **103** consists of two immiscible liquids, one being a dielectric liquid and the other one being an electrically conductive liquid. Examples of suitable electrically conductive liquids include aqueous salt solutions and molten salts. Exemplary aqueous salt solutions include 0.01 molar solutions of salts such as $CuSO_4$, LiCl, KNO_3, or NaCl. Exemplary molten salts include 1-ethyl-3-methylimidazolium tetrafluoroborate and 1-ethyl-3-methylimidazolium trifluoromethanesulfonate, which are both commercially available. In other cases the conductive liquid can comprise liquid metals such as, gallium, indium or mercury. Examples of suitable dielectric liquids include silicone oils and alkanes. Exemplary silicone oils include polydimethylsiloxane and polydiphenylsiloxane, and exemplary alkanes include nonane and heaxadecane.

Conductive and dielectric liquids are spatially separated in a plurality of distinct regions. Dielectric liquid regions **121**, **122**, **123**, **124**, **125**, **126**, **127**, **128**, **129** and conductive liquid regions **111**, **112**, **113**, **114**, **115**, **116**, **117**, **118** are arranged in a periodic alternating pattern, such that conductive and dielectric regions regularly alternate. The boundaries between immiscible liquid regions are preserved by the surface tension forces, giving fluidic body **103** an ability to move as a whole, e.g. slide along channel **202** without disturbing the arrangement and volume of the above-mentioned distinct liquid regions.

FIG. **3** presents a close-up cross-sectional view of a part **300** of the first exemplary embodiment of an apparatus **100** for converting mechanical energy into electrical energy. It can be seen in FIG. **3** that substrate **102** and electrodes **131**, **132**, **133**, **134** are covered by two layers **303** and **304** and that substrate **101** and electrodes **135**, **136**, **137**, **138** is covered by layers **301** and **302**. Layers **301** and **304** are made of a dielectric material and serve to electrically insulate conductive liquid regions **111**, **112**, **113**, **114**, **115**, **116**, **117**, **118** from the electrodes **131**, **132**, **133**, **134**, **135**, **136**, **137**, **138**. Examples of suitable dielectric materials comprise any solid dielectric such as tantalum oxide and silicon oxide, or solid polymers, such as polyimide and parylene.

An important factor in assuring an ability of fluidic body **103** to slide along the channel **202** is the mobility of the so-called contact lines. A contact line is defined as a line where three different phases such as a solid and two immiscible liquids meet each other. In particular, fluidic body **103** would have at least 32 separate contact lines located at the points where interfaces between conductive and dielectric liquid regions that make fluidic body **103** touch the walls of the channel **202**. Four of those 32 contact line locations **405**, **406**, **407**, **408** are indicated in FIG. **4**. Contact line mobility is important because contact lines tend to get pined at the solid surface, inhibiting the motion of the liquid.

In order to decrease contact line pinning the surface of dielectric layers **301** and **304** must be smooth, clean, and compositionally homogeneous. Optionally, contact line pinning can be further reduced by disposing appropriate treatment means. One example of such treatment means is a layer of a low surface energy material disposed on top of the dielectric layers. Such low-surface-energy-material layers **302** and **303** are shown in FIG. **3** and FIG. **4**.

The term low surface energy material, as used herein, refers to a material having a surface energy of about 22 dyne/cm (about 22×10^{-3} N/m) or less. Those of ordinary skill in the art would be familiar with the methods to measure the surface energy of materials. Examples of suitable materials include fluorinated polymers like polytetrafluoroethylene. Usually the low-surface-energy material is not intended to serve as an electrical insulator and would transmit electrical current. Thus a combination of a dielectric material and a low-surface-energy material is usually required to electrically insulate conductive liquid regions **111**, **112**, **113**, **114**, **115**, **116**, **117**, **118** from the electrodes **131**, **132**, **133**, **134**, **135**, **136**, **137**, **138**. However, in some cases, substrates **101** and **102** and electrodes **131**, **132**, **133**, **134**, **135**, **136**, **137**, **138** can be covered with a single material, such as Cytop® (Asahi Glass Company, Limited Corp. Tokyo, Japan), a fluoropolymer that is both an electrical insulator and low surface energy material.

Another example of contact-line-pinning-reduction means is a self-assembled molecular monolayer (SAM). Examples of suitable SAM include organic thiolates, such as dodecanethiol and octanethiol, and silanes, such as trimethoxyhexadecylsilane and dodecyltriethoxysilane. Those materials are commercially available from Sigma-Aldrich Corporation of St. Louis, Mo.

Similar to low-surface-energy materials, SAM is not intended to serve as an electrical insulator and would transmit electrical current. Thus a combination of a dielectric material and SAM is usually required to electrically insulate conductive liquid regions **111**, **112**, **113**, **114**, **115**, **116**, **117**, **118** from the electrodes **131**, **132**, **133**, **134**, **135**, **136**, **137**, **138**. However, in some cases, substrates **101** and **102** and electrodes **131**, **132**, **133**, **134**, **135**, **136**, **137**, **138** can be covered with a single SAM layer such as SAM made of n-alkyltrichlorosilanes, with very careful control of the conditions of formation, which can serve as an electrical insulator, as disclosed in the publication of D. Vuillaume, C. Boulas, J. Collet, J. V. Davidovits, and F. Rondelez, Applied Physics Letters, volume 69, page 1646, year 1996.

Yet another approach to reducing contact line pinning consists of properly arranging surface tensions of conducting and dielectric liquids to allow the dielectric liquid to form less then 100 micrometer thick lubricating layers between coatings **302** and **303** and conductive liquid regions **111**, **112**, **113**, **114**, **115**, **116**, **117**, **118**. Examples of such lubricating layers **1105** and **1106** are shown in FIG. **11**. This approach substantially eliminates contact line pinning as it essentially eliminates contact lines themselves, since in this arrangement conductive liquid regions do not contact solid directly. Formation of a lubrication layer between a liquid region and a solid is described in detail in U.S. Pat. No. 6,545,815, which is incorporated by reference herein in its entirety.

FIG. **4** presents a close-up cross-sectional view of a part **400** of apparatus **100**, which includes only one conducting liquid region **113**. FIG. **4** demonstrates that electrodes **135** and **131**, together with the conducting liquid region **113** form two substantially planar electrical capacitors **410** and **411**. The first capacitor **411** is formed by the liquid region **113** and the electrode **135**. Layers **301** and **302** serve as a spacer for the first capacitor. The second capacitor **410** is formed by the liquid region **113** and the electrode **131**. Layers **303** and **304** serve as a spacer for the second capacitor. Charges **401**, **402**, **403**, **404** accumulated at the capacitors **410** and **411** are shown schematically in FIG. **4**. Since the liquid region **113** is conductive capacitors **410** and **411** are substantially equal and electrically connected in series. Hence, their total capacitance C_0 is one half of their respective individual capacitance. In further discussion we will refer to the total capacitance C_0 associated with each pair of opposite electrodes, such as **131** and **135**, without individually mentioning each of the described above capacitors, such as **410** and **411** connected in series.

The actual value of capacitance C_0 associated with electrodes **131** and **135** depends on the relative position of region **113** with respect to electrodes **135** and **131**. When the liquid region **113** is aligned with the electrodes **135** and **131** such as to maximize the area of overlap, the capacitance reaches its maximum value. When the liquid region **113** slides away from electrodes **135** and **131** and is positioned in between the neighboring electrodes no overlap is achieved and the capacitance approaches zero.

Quite obviously the same evolution of capacitance occurs at each pair of opposite electrodes, i.e. at electrodes **131** and **135**, electrodes **132** and **136**, electrodes **133** and **137**, and electrodes **134** and **138**. Since all these pairs of electrodes are connected in parallel, one can treat the entire set of electrodes electrically coupled to connectors **105** and **106** as one variable capacitor with the total capacitance C equal to NC_0, where N is a number of electrode pairs, e.g. N=4 for exemplary embodiment **100**. The movement of fluidic body **103** along the channel **202** causes multiple variations of the total capacitance C between zero and some maximum value C_m.

There are a number of methods that can be used to extract electrical energy from a variable capacitor with alternating in time capacitance and that can be adapted for use with the current invention. Some of those methods are disclosed in U.S. Pat. Nos. 6,936,994, 4,127,804, 6,127,812, 3,094,653, 3,013,201, 4,054,826, 6,750,590, 4,897,592, 4,126,822, 2,567,373, 3,405,334, 6,255,758, 7,112,911, 4,595,852, 4,814,657, which are incorporated by reference herein in their entirety.

For illustrational purposes we will consider here a simple method based on the use of an electrical circuit means **109**, electrically coupled to electrodes **131**, **132**, **133**, **134**, **135**, **136**, **137**, **138** through electrical connectors **105** and **106**.

Electrical circuit means **109** is configured to apply bias voltage V to connectors **105** and **106** and transfer electrical current generated in response to multiple alternations in total electrical capacitance C to power consumption means **110**, which is coupled to circuit means **109** through electrical connectors **107** and **108**. In the described method electrical circuit means **109** is configured to switch bias voltage from zero to V each time the total capacitance C reaches its maximum value C_m, i.e. when the conductive liquid regions are aligned with the electrodes. The bias voltage remains switched on and equal to V as long as the total capacitance C decreases, i.e. as long as the overlap of the conductive liquid regions with the electrodes keeps decreasing. Once the total capacitance C starts to increase again the bias voltage is switched back to zero.

The total charge q accumulated by a capacitor having capacitance C and voltage differential V can be expressed as q=CV. Thus, at the first moment when the voltage V is applied to connection lines **105** and **106** the capacitor is charged and its total charge q reaches maximum value $q_m=C_mV$. At that point the total capacitor energy E reaches some value E_1 which is expressed as $E_1=0.5\,C_m, V^2$. As time progresses and fluidic body **103** slides along the channel **202** the value of capacitance C keeps decreasing and the amount of charge q accumulated by the capacitor keeps decreasing as well, thus forcing the excess charge back through the electrical circuit means **109** and against the applied voltage V. By the time the total capacitance C approaches zero, all of the initial charge q_m is forced back through the electrical circuit means **109** producing the work $E_2=q_mV=C_mV^2$. Thus, the total energy E_t generated during one alternation of the total capacitance C from zero to C_m is expressed as $E_t=E_2\ E_1=0.5\,C_mV^2$.

The total energy output of the apparatus **100** per one cycle of reversible motion of fluidic body **103** can be expressed as $E_{cycle}=M\,E_t$, where M is the total number of alternation of the total capacitance C per one cycle of reversible motion of fluidic body **103**. The value of E_{cycle} can be increased either by increasing the maximum total capacitance value C_m or by increasing the total number of alternation M. The maximum capacitance value C_m is proportional to the sum of the individual capacitances C_0 associated with each pair of electrodes. Thus, the value of C_m can be increased either by increasing the total area of electrodes **131**, **132**, **133**, **134**, **135**, **136**, **137**, **138** or by decreasing the thickness of layers **301**, **302**, **303**, and **304** which serve as capacitor spacers. The total number of alternation M of the total capacitance C per one cycle of reversible motion of fluidic body **103** is equal to the number of conductive liquid regions in fluidic body **103** minus the total number of electrode pairs.

The described above energy-converting apparatus **100** provides a very high level of tunablity with respect to coupling to environmental motion characterized by various levels of force and displacement. By increasing the length of the fluidic body, while preserving the size of individual liquid regions, one can adjust the amount of displacement that can be handled by the apparatus **100**, without affecting the force acting on the fluidic body. At the same time, by increasing the total area covered by electrodes one can adjust the level of force that can be successfully coupled to the apparatus **100**, without affecting the level of possible displacements.

The power output of the apparatus **100** can be effectively increased by increasing the number of conductive liquid regions, while decreasing the thickness of layers **301**, **302**, **303**, and **304**. Of cause, in order to preserve the relative size of the liquid regions with respect to the size of electrodes, one would need to appropriately increase the total number of electrodes as well. Such increase in power can be achieved without increasing the size or weight of the apparatus **100** if the total volume of the fluidic body **103** and the total electrode area are kept constant.

To further elucidate the above arguments let us consider the same numerical example as was already discussed earlier. For the total electrode area of 5 cm×7 cm=35 cm^2, dielectric layer thickness of 20 nm, and the working voltage of 10 V we have estimated that about 500 capacitance alternations per one cycle of environmental motion with 1 Hertz [Hz] frequency (e.g. human gait) are required in order to achieve theoretical power output on the order of 1 Watt, sufficient for operating such load as a mobile telephone.

Assuming that the length of the fluidic body **103** is three times that of the electrode area (i.e. 3×7 cm=21 cm) one can estimate that the number of required conductive liquid regions per fluidic body is 1.5 times the number of required capacitance alternations, i.e. about 750. Since dielectric and conductive liquid regions alternate, the total number of liquid regions in fluidic body **103** is 2×750=1500. Thus the length of each liquid region is about 21 cm/1500=140 micrometers. Assuming that the channel **202** has a square cross-section with the size of 100 micrometers we arrive to the typical volume of one liquid region on the order of 1.4 nanoliters. Such volumes of liquids are routinely handled in modern microfluidic devices. The total number of channels required to cover the whole available electrode area is on the order of 5 cm/100 micrometers=500. Again, parallel operation of hundreds and even thousands of channels was experimentally demonstrated in a number of modern microfluidic devices.

Actuation of the fluidic body **103** in the energy-converting apparatus **100** can be achieved by a number of means. FIGS. **5**, **6**, and **7** present cross-sectional view of a part of one exemplary embodiment of apparatus **100** where actuation of the fluidic body **103** is achieved by external application of a hydrostatic pressure. FIG. **5** presents cross-sectional view of a part **500** of an exemplary embodiment of apparatus **100** at the beginning of the reversible motion cycle. At this point hydrostatic pressure at the entrance **501** of the channel **202** is higher than the hydrostatic pressure at the exit **502** of the channel **202**. As the result the fluidic body **103** initiates sliding motion towards the channel exit **502**, as indicated schematically by arrow **503**. FIG. **6** presents cross-sectional view of a part **600** of one exemplary embodiment of apparatus **100** at the intermediate state of the reversible motion cycle. At this point hydrostatic pressure at the entrance **501** of the channel **202** is still higher than the hydrostatic pressure at the exit **502** of the channel **202**. As the result the motion of the fluidic body **103** towards channel exit **502** continues, as indicated schematically by arrow **603**. FIG. **7** presents cross-sectional view of a part **700** of one exemplary embodiment of apparatus **100** at the final stage of the reversible motion cycle. At this point hydrostatic pressure at the entrance **501** of the channel **202** is lower than the hydrostatic pressure at the exit **502** of the channel **202**. As the result the direction of motion of the fluidic body **103** is reversed and it initiates motion towards channel entrance **501**, as indicated schematically by arrow **703**.

FIGS. **8**, **9**, and **10** present cross-sectional view of a part of a second exemplary embodiment of apparatus **100** where actuation of the fluidic body **103** is achieved by decreasing the volume available for at least a part of fluidic body **103**. This can be accomplished by squeezing the substrates **101** and **102** together by the action of external pressure. In this case substrates **101** and **102** can be made of thin sheets of flexible plastics, such as polypropylene or polytetrafluoroethylene. FIG. **8** presents cross-sectional view of a part **800** of the second exemplary embodiment of apparatus **100** at the beginning of the reversible motion cycle. Arrows **801** and **802** schematically indicate applied pressure, and arrow **803** schematically indicates the direction of motion of fluidic body **103**. FIG. **9** presents cross-sectional view of a part **900** of the second exemplary embodiment of apparatus **100** at the intermediate state of the reversible motion cycle. Arrows **901** and **902** schematically indicate applied pressure, and arrow **903** schematically indicates the direction of motion of fluidic body **103**. FIG. **10** presents cross-sectional view of a part **1000** of the second exemplary embodiment of apparatus **100** at the final state of the reversible motion cycle. Arrows **1001** and **1002** schematically indicate applied pressure, and arrow **1003** schematically indicates the direction of motion of fluidic body **103**. Of cause, many other methods to actuate fluidic body **103** exist, including the action of gravity or acceleration.

FIG. **12** presents cross-sectional view of a forth exemplary embodiment **1200** of an apparatus for converting mechanical energy into electrical energy. FIG. **13** presents a plan view of a part **1300** of the same apparatus, where parts **101**, **105**, **107**, **108**, **109**, **110**, **1201** of apparatus **1200** are removed and spacers **104** and **201** are rendered semitransparent for the clarity of presentation. For simplicity, FIG. **12** and FIG. **13** present electrical connectors only schematically, not reflecting their actual physical arrangement.

The main difference between apparatus **1200** and previously described apparatus **100** is the absence of separate electrodes **135**, **136**, **137**, **138** disposed on substrate **101**. Instead, one common electrode **1201** is disposed on substrate **101**. FIG. **14** presents a close-up cross-sectional view of a part **1400** of apparatus **1200**. It can be seen in FIG. **14** that substrate **101** and electrode **1201** are covered by only one layer **302**, while substrate **102** and electrodes **131**, **132**, **133**, **134** is covered by two layers **303** and **304**. The layer **302** represents contact-line-pinning-reduction means, as discussed above, and is not configured to provide any electrical insulation between electrode **1201** and liquid regions **113**, **114**, **115**, **116**, **117**, **118**. As the result the liquid regions **113**, **114**, **115**, **116**, **117**, **118** remains in electrical contact with electrode **1201** forming an electrical capacitor with charges accumulated at the interface between the liquid regions and the electrodes **131**, **132**, **133**, **134**. Two examples of those charges **1501** and **1502** are shown in FIG. **15**. One of the advantages of such arrangement is a higher capacitance per one electrode, as only one capacitor per electrode is present, unlike the case of apparatus **100** where two capacitors in series per one electrode are present. Otherwise apparatus **1200** is similar to apparatus **100**, including various available methods of energy extraction and fluidic body actuation.

FIG. **16** presents cross-sectional view of a fifth exemplary embodiment **1600** of an apparatus for converting mechanical energy into electrical energy. FIG. **17** presents a plan view of a part **1700** of the same apparatus, where parts **101**, **105**, **1607**, **1608**, **1609**, **1610**, **1201** of apparatus **1600** are removed and spacers **104** and **201** are rendered semitransparent for the clarity of presentation. For simplicity, FIG. **16** and FIG. **17** present electrical connectors only schematically, not reflecting their actual physical arrangement.

The arrangement of apparatus **1600** is similar to that of apparatus **1200**. The apparatus **1600** comprises two substrates **101** and **102** disposed substantially co-planar and separated by spacers **104** and **201**. Spacers **104** and **201** are disposed in such a way as to form a channel **202**. One common electrode **1201** is disposed on substrate **101** and a plurality of electrodes **1631**, **1632**, **1633**, **1634** is disposed on substrate **102**. Similar to apparatus **1200** and apparatus **100** substrates **101** and **102** and spacers **104** and **201** can be made of any solid dielectric material such as glass, textolite, or a solid plastic, including polycarbonate, polypropylene, or polytetrafluoroethylene.

A movable fluidic body **103** is disposed in channel **202** and configured to slide along channel **202** past electrodes **1631**, **1632**, **1633**, **1634**. Fluidic body **103** consists of two immiscible liquids, one being a dielectric liquid and the other one being an electrically conductive liquid. Examples of suitable dielectric liquids include silicone oils and alkanes. Exemplary silicone oils include polydimethylsiloxane and polydiphenylsiloxane, and exemplary alkanes include nonane and heaxadecane.

Conductive and dielectric liquids are spatially separated in a plurality of distinct regions. Dielectric liquid regions **1621**, **1622**, **1623**, **1624**, **1625**, **1626**, **1627**, **1628**, **1629** and conductive liquid regions **1611**, **1612**, **1613**, **1614**, **1615**, **1616**, **1617**, **1618** are arranged in a periodic alternating pattern, such that conductive and dielectric regions regularly alternate. The boundaries between immiscible liquid regions are preserved by the surface tension forces, giving fluidic body **103** an ability to move as a whole, e.g. slide along channel **202** without disturbing the arrangement and volume of the above-mentioned distinct liquid regions.

FIG. **18** presents a close-up cross-sectional view of a part **1800** of apparatus **1600**. It can be seen in FIG. **18** that substrate **101** and electrode **1201** are covered only by a contact-line-pinning-reduction layer **302**, while substrate **102** and electrodes **1631**, **1632**, **1633**, **1634** are not covered by anything at all.

The main difference between apparatus **1600** and apparatus **1200** is that apparatus **1600** does not require any specially arranged bias voltage between connectors **105** and **106** in order to operate. In apparatus **1600** the electrode material and the conductive liquid material are selected in such a way as to allow spontaneous formation of electrically charged double-layer **1901** and **1902** as shown schematically in FIG. **19**. The formed double-layer prevents electrical current flow between the conductive liquid region **1901** and electrode **1902** thus forming a so-called electrochemical supercapacitor. Electrochemical supercapacitors are extensively discussed in scientific literature, including the book of B.E. Conway, Electrochemical Supercapacitors, Kliwer Academic, 1999. Those of ordinary skill in the art would be familiar with supercapacitors and the phenomenon of double-layer formation.

As mentioned above, appropriately selected electrode and conductive liquid materials are required to form a charged double-layer. The preferred electrode materials include pure carbon, or noble metals such as gold or platinum. In some preferred embodiments electrodes **1631**, **1632**, **1633**, **1634**, comprise a platinum film or a gold film. Examples of suitable electrically conductive liquids include aqueous salt solutions, and aqueous acid solutions. Exemplary aqueous salt solutions include 0.01 molar solutions of $CuSO_4$ or AgCl. Exemplary aqueous acid solutions include 0.01 molar solutions of H_2SO_4 or HCl.

Methods that can be used to extract electrical energy from apparatus **1600** are similar to those discussed in conjunction with apparatus **100**. The main difference is that electrical circuit means **1609** is not configured to apply bias voltage V to connectors **105** and **106** and serves only to transfer generated electrical current to power consumption means **1610**, which is coupled to circuit means **1609** through electrical connectors **1607** and **1608**. Optionally, an additional electrical circuit means **1601** can be used to provide external bias voltage V to connectors **105** and **106**, thus increasing the amount of charge accumulated by electrodes **1631**, **1632**, **1633**, and **1634**.

FIG. **20** presents cross-sectional view of a sixth exemplary embodiment **2000** of an apparatus for converting mechanical energy into electrical energy. For simplicity, FIG. **20** present electrical connectors only schematically, not reflecting their actual physical arrangement.

The arrangement of apparatus **2000** is similar to that of apparatus **1200**. The apparatus **2000** comprises two substrates **2001** and **2002** disposed substantially co-planar and separated by a spacer **2004**. Spacer **2004** is arranged in such a way as to form a channel **2050**. One common electrode **2005** is disposed on substrate **2001** and a plurality of electrodes **2031**, **2032**, **2033**, **2034** is disposed on substrate **2002**. Similar to apparatus **1200** and apparatus **100** substrates **2001** and **20202** and a spacer **2004** can be made of any solid dielectric material such as glass, textolite, or a solid plastic, including polycarbonate, polypropylene, or polytetrafluoroethylene.

Fluidic body **2003** consists of two immiscible liquids, one being a dielectric liquid and the other one being an electrically conductive liquid. Examples of suitable dielectric liquids include silicone oils and alkanes. Exemplary silicone oils include polydimethylsiloxane and polydiphenylsiloxane, and exemplary alkanes include nonane and heaxadecane. Examples of suitable electrically conductive liquids include aqueous salt solutions and molten salts. Exemplary aqueous salt solutions include 0.01 molar solutions of salts such as $CuSO_4$, LiCl, KNO_3, or NaCl. Exemplary molten salts include 1-ethyl-3-methylimidazolium tetrafluoroborate and 1-ethyl-3-methylimidazolium trifluoromethanesulfonate, which are both commercially available. In other cases the conductive liquid can comprise liquid metals such as, gallium, indium or mercury.

Conductive and dielectric liquids are spatially separated in a plurality of distinct regions. Dielectric liquid regions **2021**, **2022**, **2023**, **2024**, **2025**, **2026**, **2027**, **2028**, **2029** and conductive liquid regions **2011**, **2012**, **2013**, **2014**, **2015**, **2016**, **2017**, **2018** are arranged in a periodic alternating pattern, such that conductive and dielectric regions regularly alternate. The boundaries between immiscible liquid regions are preserved by the surface tension forces, giving fluidic body **2003** an ability to move as a whole, i.e. without disturbing the arrangement and volume of the above-mentioned distinct liquid regions.

The main difference between apparatus **2000** and previously considered apparatus **1200** is that in apparatus **2000** fluidic body **2003** is permanently attached to substrate **2001** by the action of surface tension forces. Substrate **2001** is adapted to slide with respect to substrate **2002** as schematically indicated in FIG. **20** by arrow **2006**. Thus the fluidic body **2003** is capable of moving past electrodes **2031**, **2032**, **2033**, **2034** in pretty much the same way as is in apparatus **1200**.

FIG. **21** presents a close-up cross-sectional view of a part **2100** of apparatus **2000**. It can be seen in FIG. **21** that substrate **2001** and electrode **2005** are covered by layer **2101**, while substrate **2002** and electrodes **2031**, **2032**, **2033**, **2034** are covered by a dielectric layer **304** and a contact-line-pinning-reduction layer **303**. Layer **2101** consists of hydrophilic regions **2111**, **2112**, **2113** and hydrophobic regions **2114**, **2115** which are arranged in an alternating manner. The action of surface tension forces attach conductive liquid regions **2011**, **2012**, **2013** to hydrophilic surface regions **2111**, **2112**, **2113** and dielectric liquid regions **2022** and **2023** to hydrophobic surface regions **2114** and **2115**. As the result the fluidic body **2003** gets permanently attached to substrate **2001**.

Actuation of fluidic body **2003** in apparatus **2000** can be done by a variety of forces applied to substrate **2001**, including gravity, inertia, and pressure. Methods that can be used to extract electrical energy from apparatus **2000** are the same as those discussed in conjunction with apparatus **100** and apparatus **1200**.

FIG. **22** presents cross-sectional view of a seventh exemplary embodiment **2200** of an apparatus for converting mechanical energy into electrical energy. For simplicity, FIG. **22** present electrical connectors only schematically, not reflecting their actual physical arrangement.

The arrangement of apparatus **2000** is very similar to that of apparatus **2000**, except that the phenomenon of a double-layer formation as in apparatus **1600** is employed. Similar to apparatus **2000** fluidic body **2203** is permanently attached to movable substrate **2201** by the action of surface tension forces. Similar to apparatus **1600** fluidic body **2203** is in direct contact with electrodes **2231**, **2232**, **2233**, **2234**. The electrode material and the conductive liquid material are selected to facilitate electrical double-layer formation as discussed above.

Actuation of fluidic body **2203** in apparatus **2200** can be done similar to apparatus **2000** by a variety of forces applied to substrate **2201**, including gravity, inertia, and pressure. Methods that can be used to extract electrical energy from apparatus **2200** are the same as those discussed in conjunction with apparatus **1600**.

Another embodiment of the current invention is a first method of use. The method comprises converting mechanical energy into electrical energy, which includes the following steps. (i) Providing circuit means for applying a bias voltage to plurality of electrodes and transferring generated electrical current from said electrodes to power consumption means. An example of those circuit means **109** and an example of power consumption means **110** are shown in FIG. **1** in conjunction with exemplary embodiment of apparatus **100**. (ii) Applying a bias voltage to said electrodes and, as the result, providing electrical charge to the electrodes and generating electrical field in the space between electrodes. (ii) Reversibly moving a fluidic body comprising alternating conductive and dielectric liquid regions against electrostatic forces generated by said electrical field, thus causing multiple variations of electrical field per each cycle of reversible motion of fluidic body. Since the amount of charge on the electrodes and the field strength are intimately related, electrical field variations cause charge variations, which, in turn, can be converted into useful electrical current. (iv) Transferring electrical current generated by the multiple alternations of the accumulated charge to power consumption means.

Yet another embodiment of the current invention is a second method of use. The method comprises converting mechanical energy into electrical energy, which includes the following steps. (i) Providing circuit means for transferring generated electrical current from a plurality of electrodes to power consumption means. An example of those circuit means **1609** and an example of power consumption means **1610** are shown in FIG. **16** in conjunction with exemplary embodiment of apparatus **1600**. (ii) Generating electrical field between said electrodes by forming electrical double-layer between said electrodes and a fluidic body comprising alternating conductive and dielectric liquid regions. (ii) Reversibly moving said fluidic body against electrostatic forces generated by said electrical field, thus causing multiple variations of the electrical field per each cycle of reversible motion of fluidic body. Since the amount of charge on the electrodes and the field strength are intimately related, electrical field variations cause charge variations, which, in turn, can be converted into useful electrical current. (iv) Transferring electrical current generated by the multiple alternations of the accumulated charge to power consumption means.

Yet another embodiment of the current invention is a method of manufacturing of mechanical-to-electrical energy converting device, comprising the following steps. (i) Forming a plurality of electrodes over one or more substrates. In some cases those substrates can be flexible polymeric materials, such as polypropylene, while in the other cases they might be rigid plates, such as a glass or textolite. Electrodes can be formed of various conducting materials including carbon or noble metals.

(ii) Forming a fluidic body comprising a plurality of alternating conductive and dielectric liquid regions. Examples of suitable dielectric liquids include silicone oils and alkanes. Exemplary silicone oils include polydimethylsiloxane and polydiphenylsiloxane, and exemplary alkanes include nonane and heaxadecane. Examples of suitable electrically conductive liquids include aqueous salt solutions and molten salts. Exemplary aqueous salt solutions include 0.01 molar solutions of salts such as $CuSO_4$, LiCl, KNO_3, or NaCl. Exemplary molten salts include 1-ethyl-3-methylimidazolium tetrafluoroborate and 1-ethyl-3-methylimidazolium trifluoromethanesulfonate, which are both commercially available. In other cases the conductive liquid can comprise liquid metals such as, gallium, indium or mercury.

(iii) Positioning said fluidic body in close proximity to said plurality of electrodes. (iv) Electrically coupling said plurality of electrodes to electrical circuit means for transferring electrical current generated by said energy converting device to power consumption means.

Although the present invention has been described in detail, those of ordinary skill in the art should understand that they could make various changes, substitutions and alterations herein without departing from the scope of the invention.

What is claimed is:

1. An apparatus for converting mechanical energy into electrical energy comprising:

a plurality of electrodes disposed over at least one substrate and being arranged in a predetermined pattern;

a fluidic body comprising at least two immiscible liquids, at least one of said immiscible liquids being an electrically conductive liquid and at least one of said immiscible liquids being a dielectric liquid;

said fluidic body having at least one dielectric liquid and at least one electrically conductive liquid out of said at least two immiscible liquids spatially separated in a plurality of distinct regions arranged in a predetermined alternating pattern;

said fluidic body being disposed in close proximity to said plurality of electrodes and being electrically insulated from at least one electrode out of said plurality of electrodes;

said fluidic body being adapted to reversibly move as a whole under the action of an applied mechanical force, wherein

said motion as a whole of said fluidic body preserves relative positions of the liquid regions with respect to each other, so that said predetermined alternating pattern remains substantially intact during the motion, wherein

each cycle of said reversible motion of said fluidic body causing multiple alternations of the area of overlap between the conductive liquid regions of said fluidic body and at least one electrically insulated electrode;

said multiple alternations of the area of overlap causing multiple alternations of electrical capacitance between at least two electrodes of said plurality of electrodes;

an electrical circuit means, electrically coupled to said at least two electrodes of said plurality of electrodes, wherein

said electrical circuit means is configured to apply bias voltage to said at least two electrodes and transfer electrical current generated in response to said multiple alternations in electrical capacitance to power consumption means.

2. The apparatus of claim **1**, wherein said mechanical force is produced by externally applied hydrostatic pressure.

3. The apparatus of claim **1**, wherein said mechanical force is produced by action of gravity or inertia, or by any combination thereof.

4. The apparatus of claim **1**, wherein said mechanical force is produced by changing the volume of the region of space occupied by at least a portion of said fluidic body.

5. The apparatus of claim **1**, wherein electrical insulation between said fluidic body and said at least one electrode is achieved by means of one or more layers of substantially non-conductive material disposed in between said fluidic body and said at least one electrode.

6. The apparatus of claim **5**, wherein said substantially non-conductive material is configured to minimize contact line pinning associated with said reversible motion of said fluidic body.

7. The apparatus of claim **5**, wherein said substantially non-conductive material comprises one or more self-assembled molecular monolayers.

8. The apparatus of claim **5**, wherein said substantially non-conductive material comprises one or more layers of a dielectric material.

9. The apparatus of claim **8**, wherein said dielectric material comprises tantalum oxide.

10. The apparatus of claim **8**, wherein said dielectric material comprises silicon oxide.

11. The apparatus of claim **8**, wherein said substantially non-conductive material comprises a combination of one or more layers of a dielectric material and one or more self-assembled molecular monolayers.

12. The apparatus of claim **5**, wherein at least one dielectric liquid of said at least two immiscible liquids is configured to form less then 100 micrometer thick lubricating layer between said substantially non-conductive material and said fluidic body, so as to substantially eliminate contact line pinning associated with said reversible motion of said fluidic body.

13. The apparatus of claim **1**, wherein electrical insulation between said fluidic body and said at least one electrode is achieved through spontaneous formation of a charged electrical double-layer between said at least one electrode and the conducting liquid regions of said fluidic body.

14. The apparatus of claim **13**, wherein at least one electrode of said plurality of electrodes incorporates at least one treatment means for minimizing contact line pinning associated with said reversible motion of said fluidic body.

15. The apparatus of claim **14**, wherein said at least one treatment means comprises one or more self-assembled molecular monolayers disposed on the surface of said at least one electrode.

16. The apparatus of claim **13**, wherein at least one dielectric liquid of said at least two immiscible liquids is configured to form less then 100 micrometer thick lubricating layer between said at least one electrode and said fluidic body, so as to substantially eliminate contact line pinning associated with said reversible motion of said fluidic body.

17. The apparatus of claim **1**, wherein

said fluidic body is substantially attached to at least one movable member by the action of surface tension forces;

said movable member being adapted to reversibly move under the action of an applied mechanical force, wherein

said reversible motion of said movable member causes said fluidic body to reversibly move as a whole in concert with said movable member, wherein each cycle of said reversible motion as a whole of said fluidic body causes multiple alternations of electrical capacitance between at least two electrodes of said plurality of electrodes.

18. The apparatus of claim **1**, wherein said at least two immiscible liquids are spatially separated in said plurality of distinct regions by the action of surface tension forces.

19. The apparatus of claim **1**, wherein said fluidic body is confined to a channel.

20. The apparatus of claim **1**, wherein said at least one conductive liquid is aqueous solution of water-soluble salt and said at least one dielectric liquid is silicone oil.

21. The apparatus of claim **1**, wherein said at least one substrate consist of one or more layers of flexible material.

22. An apparatus for converting mechanical energy into electrical energy comprising:

a plurality of electrodes disposed over at least one substrate and being arranged in a predetermined pattern;

a fluidic body comprising at least two immiscible liquids, at least one of said immiscible liquids being an electrically conductive liquid and at least one of said immiscible liquids being a dielectric liquid;

said fluidic body having at least one dielectric liquid and at least one electrically conductive liquid out of said at least two immiscible liquids spatially separated in a plurality of distinct regions arranged in a predetermined alternating pattern;

said fluidic body being disposed in close proximity to said plurality of electrodes;

said at least one electrically conductive liquid configured to spontaneously form charged electrical double-layer between at least one electrode of said plurality of electrodes and the conducting liquid regions of said fluidic body;

said charged electrical double-layer causing spontaneous accumulation of electrical charge by said at least one electrode;

said fluidic body being adapted to reversibly move as a whole under the action of an applied mechanical force, wherein

said motion as a whole of said fluidic body preserves relative positions of the liquid regions with respect to each other, so that said predetermined alternating pattern remains substantially intact during the motion, wherein

each cycle of said reversible motion of said fluidic body causing multiple alternations of the amount of said electrical charge accumulated by said at least one electrode;

an electrical circuit means, electrically coupled to said at least one electrode, and configured to transfer electrical current generated in response to said multiple alternations of said electrical charge to power consumption means.

23. The apparatus of claim **22**, wherein said mechanical force is produced by externally applied hydrostatic pressure.

24. The apparatus of claim **22**, wherein said mechanical force is produced by action of gravity or inertia, or by any combination thereof.

25. The apparatus of claim **22**, wherein said mechanical force is produced by changing the volume of the region of space occupied by at least a portion of said fluidic body.

26. The apparatus of claim **22**, wherein at least one electrode of said plurality of electrodes incorporates at least one treatment means for minimizing contact line pinning associated with said reversible motion of said fluidic body.

27. The apparatus of claim **26**, wherein said at least one treatment means comprises one or more self-assembled molecular monolayers disposed on the surface of said at least one electrode.

28. The apparatus of claim **22**, wherein at least one dielectric liquid of said at least two immiscible liquids is configured to form less then 100 micrometer thick lubricating layer between said at least one electrode and said fluidic body, so as to substantially eliminate contact line pinning associated with said reversible motion of said fluidic body.

29. The apparatus of claim **22**, further comprising second electrical circuit means, electrically coupled to said at least one electrode, and configured to apply bias voltage to said at least one electrode, so as to increase the amount of charge accumulated by said at least one electrode.

30. The apparatus of claim **22**, wherein

said fluidic body is substantially attached to at least one movable member by the action of surface tension forces;

said movable member being adapted to reversibly move under the action of an applied mechanical force, wherein

said reversible motion of said movable member causes said fluidic body to reversibly move as a whole in concert with said movable member, wherein

each cycle of said reversible motion as a whole of said fluidic body causes multiple alternations of the amount of electrical charge accumulated by said at least one electrode of said plurality of electrodes.

31. The apparatus of claim **22**, wherein said at least two immiscible liquids are spatially separated in said plurality of distinct regions by the action of surface tension forces.

32. The apparatus of claim **22**, wherein said fluidic body is confined to a channel.

33. The apparatus of claim **22**, wherein said at least one conductive liquid is aqueous solution of water-soluble salt and said at least one dielectric liquid is silicone oil.

34. The apparatus of claim **22**, wherein said at least one substrate consist of one or more layers of flexible material.

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