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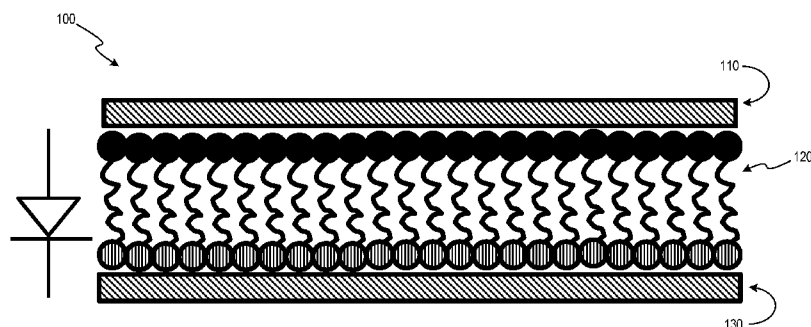


FIG. 1

(57) **Abstract:** A device for harnessing energy is described. The device may include at least one layer of antennas, a first electrode having a first side and a second side, at least one layer of zwitterionic molecules and a second electrode. The at least one layer of antennas is in electrical contact with the first side of the first electrode. The at least one layer of zwitterionic molecules is in electrical contact with the second side of the first electrode and the second electrode such that the at least one layer of zwitterionic molecules provides a selectively activated electrical conduction path between the first electrode and the second electrode.



ULTRAFAST, MOLECULARLY RECTIFIED NANO-ANTENNAS**CROSS-REFERENCE TO RELATED APPLICATIONS**

[0001] This application claims the priority benefit of United States Provisional Patent Application No. 61/839,185, filed June 25, 2013 and entitled “ULTRAFAST, MOLECULARLY RECTIFIED NANO-ANTENNAS,” the contents of which are incorporated herein by reference in its entirety.

BACKGROUND

[0002] Many technologies exist for harvesting solar energy including photovoltaics and solar-thermal energy generation. However, such technologies may not be particularly efficient at converting solar energy into electricity.

[0003] An example antenna may be configured to operate by receiving electromagnetic radiation at a resonant frequency and converting the radiation into an oscillating electric current. A nano-antenna can be described as an antenna having nanometer-sized dimensions. The nano-antenna may typically be resonant at infrared (IR) or visible frequencies. The present disclosure appreciates that nano-antennas may offer a potential solution for more efficiently harvesting electromagnetic radiation in the IR and visible frequency spectra. One of the challenges appreciated by the present disclosure is that the efficiency of nano-antennas in harvesting solar energy may be limited by the ability to effectively rectify the high frequency currents produced by the nano-antennas.

SUMMARY

[0004] This disclosure is not limited to the particular systems, devices and methods described, as these may vary. The terminology used in the description is for the

purpose of describing the particular versions or embodiments only, and is not intended to limit the scope of the present disclosure.

[0005] As used in this document, the singular forms “a,” “an,” and “the” include plural references unless the context clearly dictates otherwise. Unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by one of ordinary skill in the art. Nothing in this disclosure is to be construed as an admission that the embodiments described in this disclosure are not entitled to antedate such disclosure by virtue of prior invention. As used in this document, the term “comprising” means “including, but not limited to.”

[0006] In some embodiments, a device for rectifying a high-frequency signal may include a first electrode and a second electrode. In addition, the device may also include at least one layer of zwitterionic molecules. The zwitterionic molecules may be arranged in electrical contact with the first electrode and the second electrode. The arrangement of zwitterionic molecules may be such that an electrical conduction path between the first electrode and the second electrode is effectively provided.

[0007] In some embodiments, a device for harnessing energy may include a first electrode having a first side and a second side. In addition, the device may also have a second electrode. At least one layer of antennas may be arranged such that they are in electrical contact with the first side of the first electrode. The device may also include at least one layer of zwitterionic molecules. The zwitterionic molecules may be arranged in electrical contact with the second side of the first electrode and the second electrode. Thus, the zwitterionic molecules may effectively provide an electrical conduction path between the first electrode and the second electrode.

[0008] In some embodiments, a system for harnessing light energy may include a first device, a second device, and a third device. The first device may have at least one layer

of nano-antennas and may be configured to convert light energy into a high-frequency electric signal. The second device may be operably coupled to the first device. In addition, the second device may be configured to rectify the high-frequency electric signal emanating from the first device. The third device may be operably coupled to the second device. In addition, the third device may be configured to store energy. In certain embodiments, the second device may include a device having a first electrode, at least one layer of zwitterionic molecules, and a second electrode. The zwitterionic molecules may be in electrical contact with the first electrode and the second electrode. Such electrical contact may provide an electrical conduction path between the first electrode and the second electrode. In various embodiments, the third device may include one or more of a battery, a capacitor, a supercapacitor, a superconducting magnetic energy storage, a fuel cell, and the like.

[0009] In various embodiments, methods of rectifying a high-frequency signal are described. Such methods may include transmitting the high-frequency signal through at least one layer of zwitterionic molecules. In some embodiments, transmitting the high-frequency signal may be facilitated with an array of antennas. The high frequency signal may be a range of about 300 GHz to about 10 PHz.

[0010] In additional embodiments, methods for harnessing light energy are described. Various methods may include converting light into a high-frequency electric signal. Various methods may also include rectifying the high-frequency electric signal to form a rectified signal having an energy. Various methods may further include storing the energy of the rectified signal in an energy storage device. In some embodiments, converting the light may include using at least one array of antennas that are configured to have a resonance frequency in a range of about 300 GHz to about 10 PHz.

[0011] In some embodiments, methods of making a device for rectifying a high-frequency signal are described. Various methods may include disposing at least one layer of

zwitterionic molecules on a first electrode and contacting a second electrode with the at least one layer of zwitterionic molecules. Contacting may be configured such that the at least one layer of zwitterionic molecules provides an electrical conduction path between the first electrode and the second electrode.

[0012] In various embodiments, methods for making a device for harnessing energy are described. Various methods may include disposing an array of antennas in a porous membrane. Various methods may also include disposing a first electrode having a first side and a second side on the porous membrane. Disposing may be configured such that the first side is in electric contact with the array of antennas. Various methods may further include disposing at least one layer of zwitterionic molecules on the first electrode such that the at least one layer of zwitterionic molecules is in electrical contact with the second side of the first electrode. In addition, various methods may include contacting a second electrode with the at least one layer of zwitterionic molecules such that the at least one layer of zwitterionic molecules provides an electrical conduction path between the first electrode and the second electrode.

BRIEF DESCRIPTION OF DRAWINGS

[0013] In the present disclosure, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be used, and other changes may be made, without departing from the spirit or scope of the subject matter presented herein. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the Figures, can be

arranged, substituted, combined, separated, and designed in a wide variety of different configurations, all of which are explicitly contemplated herein.

[0014] Figure 1 depicts an illustrative schematic of a device for rectifying a high-frequency signal, arranged in accordance with various embodiments.

[0015] Figure 2 depicts an illustrative schematic of a device for harnessing energy, arranged in accordance with some embodiments.

[0016] Figure 3 depicts a schematic of an illustrative nano-antenna, arranged in accordance with various embodiments.

[0017] Figure 4 depicts a schematic diagram of an illustrative system for harnessing light energy in accordance with some embodiments.

DETAILED DESCRIPTION

[0018] Described herein are devices and systems generally directed to harnessing solar energy, and methods of making such devices and systems. As such, some systems may include a device for converting light energy into high-frequency electric signals, a device for rectifying the high-frequency electric signals, and a device for storing the energy available from the rectified high-frequency electric signals.

[0019] A typical device for converting light energy into high-frequency electric signals may include at least one layer of antennas having resonant frequencies in the infrared and visible ranges. As described herein, the term “high-frequency signal” refers to alternating electric signals (currents or voltages) having frequency of more than about 100 gigahertz (GHz). In the present disclosure, the terms “high-frequency signals”, and “high-frequency currents” may be used interchangeably. When radiation is incident on a layer of antennas having a suitable resonant frequency, the antennas may convert the radiation into electric signals (e.g., currents). The electric signals are, typically, alternating currents having

substantially the same frequency as that of the incident radiation. If the radiation is in the visible or infrared regions of the electromagnetic spectrum, the frequency of the signals may be in a range of about 300 GHz to about 10 petahertz (PHz). Alternating currents having such high frequencies are generally not suitable for transmission using available technology. As such, it may be desirable to rectify these high-frequency currents to obtain a direct current (DC) signal that may be transmitted to an energy storage device such as a battery or a supercapacitor.

[0020] Rectification of high-frequency signals may be achieved using devices that may include at least one layer of suitable zwitterionic molecules sandwiched between two electrodes for electrical connectivity. A zwitterionic molecule is typically a neutral molecule having formal unit electrical charges of opposite sign within the molecule. In various instances, zwitterions may be referred to as inner salts. The layer may be aligned such that charges with the same sign may be positioned at a first electrode and charges with the opposite sign may be positioned at a second electrode. Thus, a layer of suitable zwitterionic molecules may act to rectify a high-frequency electric signal by limiting current passing in one direction across the layer, while allowing current passing in the opposite direction across the layer. Rectification provided by a particular configuration may be measured in terms of rectification ratio, which can be defined by the formula:

$$RR = \frac{I(V)}{-I(-V)} - (1)$$

[0021] where $I(V)$ is the current flow by the device when a voltage V is applied across the device. As such it may be desirable that a device for rectifying high-frequency signals allows transmission of substantially all signals in one direction (e.g., forward bias or active conduction) and restrict transmission (e.g., reverse bias or blocking conduction) of substantially all signals in the opposite direction, thereby having a high RR . Typically, a suitable zwitterionic molecule may have a donor-bridge-acceptor configuration. The donor

may be described as, in general, a negatively charged moiety that can readily donate an electron when a suitable bias is applied. The acceptor may be described as, in general, a positively charged moiety that can readily accept an electron when a suitable bias is applied. The donor and acceptor moieties can be linked by a bridge that acts as a tunneling barrier so as to allow electron transport in one direction (from donor to acceptor) under suitable bias, but restrict electron transport in the opposite direction (acceptor to donor).

[0022] Some embodiments are directed to devices for rectifying high-frequency signal. Figure 1 depicts an illustrative schematic of a device for rectifying a high-frequency signal, arranged in accordance with various embodiments. In some embodiments, a device **100** for rectifying a high-frequency signal may include a first electrode **110**, at least one layer **120** of zwitterionic molecules, and a second electrode **130**. The at least one layer **120** of zwitterionic molecules may be disposed such that the at least one layer **120** of zwitterionic molecules is configured in electrical contact with the first electrode **110** and the second electrode **130**, and provides a selectively activated electrical conduction path between the first electrode **110** and the second electrode **130**.

[0023] In some embodiments, the first electrode **110** and/or the second electrode **130** may include one or more of a metal, a metal alloy, a semi-metal, a conductor, a conducting polymer, a doped semiconductor, a doped metal oxide, a carbon allotrope, and the like. Examples of various materials that may be used for the first electrode **110** and/or the second electrode **130** include, but are not limited to, gold, platinum, iridium, titanium, aluminum, magnesium, copper, silver, tin, an alloy thereof, graphite, graphene, doped silicon, cadmium telluride, doped germanium, gallium arsenide, indium-gallium, indium-gallium arsenide, indium gallium nitride, indium gallium phosphide, copper indium gallium selenide, doped zinc oxide, fluorine doped tin-oxide, polypyrrole, polyaniline, poly(p-phenylene vinylene), poly(3,4-ethylenedioxythiophene), and so forth, or any combination thereof.

[0024] In some embodiments, different materials may be used for the first electrode **110** and the second electrode **130**. For example, in certain embodiments, the first electrode **110** may be aluminum and the second electrode **130** may be aluminum-coated magnesium. In further embodiments, the first electrode **110** may be platinum and the second electrode **130** may be silver-coated magnesium.

[0025] In some embodiments, both the first electrode **110** and the second electrode **130** may have the same material. For example, in certain embodiments, both the first electrode **110** and the second electrode **130** may be of gold. In another example, both the first electrode **110** and the second electrode **130** may be made of platinum. In some embodiments, both the first electrode **110** and the second electrode **130** may be made of gallium indium nitride.

[0026] In various embodiments, the molecules of the layer of zwitterionic molecules **120** may be, for example, hexadecylquinolinium tricyanoquinodimethanide (C₁₆H₃₃-γQ₃CNQ), 2,6-dibutylaminophenylvinyl-1-butylpyridinium iodide, dimethylanilinoaza[C]-fullerene, fullerene-bis-[4-diphenylamino-4''-(N-ethyl-N-2''-ethyl)-amino-1,4-diphenyl-1,3-butadiene] malonate, N-3-γ-Pyrodylaza[60]fulleroid (C₆₀NPy), N-(10-nonadecyl)-N-(2-ferrocenylethyl)pyrenyle-3,4,9,10-bis (dicarboxyimide), 4,5-dipentyl-50-methyltetra-thiafulvalen-40-methyloxy-2,4,5-trinitro-9-dicyanomethylenefluorene-7-(3-sulfonylpropionate), 29-amino-4-ethynylphenyl-49-ethynylphenyl-59-nitro-1-benzenethiol, and the like. It is to be understood that the choice of suitable metal electrodes is determined by the particular choice of zwitterionic molecule based on the particular HOMO, LUMO and Fermi levels of the materials being used. For example, gold may be used for both the first electrode **110** and the second electrode **130** when the layer of zwitterionic molecules **120** has C₁₆H₃₃-γQ₃CNQ.

[0027] Further embodiments may be directed to devices for harnessing energy. Figure 2 depicts an illustrative schematic of a device for harnessing energy, arranged in accordance with some embodiments. In some embodiments, example devices for harnessing energy may include at least one layer of antennas **240**, a first electrode **110** having a first side and a second side, at least one layer **120** of zwitterionic molecules, and a second electrode **130**. The at least one layer of antennas **240** may be arranged in electrical contact with the first side of the first electrode **110**. The at least one layer **120** of zwitterionic molecules may be arranged in electrical contact with the second side of the first electrode **110** and the second electrode **130** such that the at least one layer of zwitterionic molecules effectively provides a selectively activated electrical conduction path between the first electrode **110** and the second electrode **130**. In various embodiments, example devices may be configured to harness light energy (radiation in infrared and visible region of the electromagnetic spectrum).

[0028] In various embodiments, the at least one layer of antennas **240** may include any device now known or later developed that is configured to emit and/or receive waves of energy, such as, for example, electromagnetic energy. In some embodiments, the antennas may be configured to have a resonant frequency in a range of about 300 GHz to about 10 PHz. Specific examples of the resonant frequency may include, but are not limited to, about 300 GHz, about 500 GHz, about 1 terahertz (THz), about 10 THz, about 25 THz, about 50 THz, about 100 THz, about 200 THz, about 300 THz, about 400 THz, about 500 THz, about 600 THz, about 700 THz, about 800 THz, about 900 THz, about 1 PHz, about 10 PHz, or any values or ranges between any two of these values (including endpoints). The wavelength for visible and infrared frequencies is in a range of about 300 micrometers (μm) to about 30 nanometers (nm) and the required physical length of antennas resonating at visible and infrared frequencies is on the order of nanometers. As such, antennas resonating at visible and infrared frequencies may be referred as nano-antennas.

[0029] Figure 3 depicts a schematic of an illustrative nano-antenna, arranged in accordance with various embodiments. In some embodiments, an example nano-antenna **300** may include a porous membrane **301**, a plurality of nanowires **302** disposed in the porous membrane **301**, and a monolayer **303** of nanospheres **304** with substantially the same diameter as the nanowires **302**. The monolayer **303** of nanospheres **304** may also be electrically in series with the nanowires.

[0030] In some embodiments, the nano-antenna **310** may have a resonant frequency in a range of about 100 GHz to about 10 PHz, including, but not limited to, about 100 GHz, about 200 GHz, about 300 GHz, about 400 GHz, about 500 GHz, about 1 THz, about 10 THz, about 25 THz, about 50 THz, about 100 THz, about 200 THz, about 300 THz, about 400 THz, about 500 THz, about 600 THz, about 700 THz, about 800 THz, about 900 THz, about 1 PHz, about 10 PHz, or any value or range between any two of these values (including endpoints). As described herein, the term “nanowires” generally refers to wires having a diameter in a range of about 1 nanometer (nm) to about 1 micron (μm), and a length in a range of about 10 nm to about 100 μm . As described herein, the term “nanospheres” generally refers to spheres having a diameter in a range of about 1 nm to about 1 μm .

[0031] It will be understood that in a given plurality of structures such as nanowires or nanospheres, dimensions associated with the particular structure may vary depending on the particular fabrication technique used and as such are to be considered as average dimensions. In some embodiments, the nano-antenna **300** may be in the form of a dipole, a monopole, an extra short dipole, a linear model, a Yagi-Uda array, a log-periodic array, a collinear array, or a combination thereof. In some embodiments, the nano-antenna **300** may be a $\frac{1}{2}$ -wavelength dipole, a $\frac{1}{4}$ -wavelength dipole, or an integer multiple of a $\frac{1}{2}$ -wavelength dipole.

[0032] In some embodiments, the porous membrane **301** may be made of, for example alumina, silicon, silicon dioxide, polymethyl methacralate (PMMA), and so forth.

[0033] In some embodiments, the nano-antenna **300** may additionally have a polymer layer **305** arranged in electrical contact with the monolayer of nanospheres. In certain embodiments, the polymer layer **305** may be an insulating layer made from, for example, polydimethyl siloxane (PDMS), PMMA, polyethylene (PE), polystyrene (PS), polypropylene, polyethylene terephthalate (PET), polycarbonate, polyacrylate, neoprene, nylon, polyvinyl chloride (PVC), polyvinyl butyral (PVB), polyacrylonitrile, silicone, combinations of any two or more, and/or the like. In other embodiments, the polymer layer **305** may be a conductive layer made from, for example, polyacetylene, polypyrrole, polyaniline, poly(p-phenylene vinylene), polythiophenes, and/or the like.

[0034] Because the layer of antennas **240** may be configured to harness light energy, in various embodiments, it may be desirable for the nano-antenna **300** to be substantially transparent or substantially translucent to visible and infrared frequencies. In some embodiments, one or more of the porous membrane **301**, the nanowires **302**, the monolayer **303** of nanospheres **304**, and the polymer layer **305** may be substantially transparent. In other embodiments, one or more of the porous membrane **301**, the nanowires **302**, the monolayer **303** of nanospheres **304**, and the polymer layer **305** may be substantially translucent.

[0035] In various embodiments, the nanowires **302** may be configured to be operable as a nano-antenna **300** for which the resonant frequency may be determined by the physical length of the nanowires **302**. Depending on the specific application, it may be required to lengthen or shorten the electrical length of the nano-antenna **300** corresponding to its use for a certain frequency or a specific range of frequencies. A capacitive reactance may be added by adding a monolayer **303** of dielectric nanospheres **304** electrically in series with

nanowires **302**. An inductive reactance may be added by adding a monolayer **303** of conducting nanospheres **304** electrically coupled in series with the nanowires **302**. In some embodiments, the nanospheres **304** may be made of dielectric materials such as, for example, polymers, glasses, silica, carbohydrates, lignin, combinations thereof, and/or the like. In other embodiments, the nanospheres **304** may be made of conductive materials including, without limitation, metals, conductive polymers, and/or the like. In certain embodiments, where transparency is desired, the nanospheres **304** may be made of a transparent polymer material.

[0036] The resonant frequency of a nano-antenna **300** is dependent on the dimensions of the nanowires **302** and the nanospheres **304** that form the nano-antenna. In some embodiments, the nanowires **302** may have an aspect ratio (ratio of length to diameter) of about 3:1 to provide appropriate impedance to the nano-antenna **300**. In some embodiments, the aspect ratio of the nanowires may be about 5:1, about 7:1, about 10:1, about 12:1, about 15:1, about 17:1, about 20:1, about 25:1, or any range between any two of these values (including endpoints).

[0037] In certain embodiments, the nanowires **302** may be made of a metal such as, for example, gold (Au), silver (Ag), iron (Fe), titanium (Ti), platinum (Pt), copper (Cu), zinc (Zn), aluminum (Al), manganese (Mn), cobalt (Co), nickel (Ni), any combination of the foregoing, any alloy of the foregoing, and/or the like. In other embodiments, the nanowires **304** may be made of a doped semiconductor such as, for example, boron-doped silicon, phosphorous-doped silicon, and/or the like. In yet other embodiments, the nanowires **302** may be of a doped metal oxide such as, for example, fluorine-doped tin oxide, indium-doped tin oxide, and/or the like. A skilled artisan will realize, in light of the present disclosure, that a nano-antenna **300** may be formed by combining nanowires **302** of any of the appropriate materials listed herein in any combination thereof.

[0038] The reactance offered by the nanospheres **304** is dependent on the size of the nanospheres. Depending on the application, the size of the nanowires **302**, and the required resonant frequency, the nanospheres **304** may have a diameter in a range of about 5 nm to about 50 nm, about 50 nm to about 100 nm, about 100 nm to about 200 nm, about 200 nm to about 300 nm, about 300 nm to about 400 nm, about 400 nm to about 500 nm, or any combination thereof. Specific examples of diameters may include about 5 nm, about 50 nm, about 100 nm, about 200 nm, about 300 nm, about 400 nm, about 500 nm, and ranges between any two of these values (including endpoints).

[0039] In some embodiments, the nanospheres **304** may be made of dielectric materials such as, for example, polymers, glasses, silica, carbohydrates, lignins, combinations thereof, and/or the like. In other embodiments, the nanospheres **304** may be made of conductive materials including, without limitation, metals, metal alloys, doped semiconductors, conductive polymers and/or the like. In certain embodiments, where transparency is desired, the nanospheres **304** may be of a transparent polymer material.

[0040] In various embodiments, it may be desirable to have an intermediate conductive layer (not shown) to form an electrical contact between the second side of the first electrode **110** and the at least one layer **120** of zwitterionic molecules for material compatibility and/or matching Fermi levels between the zwitterionic molecules and the first electrode **110**. Material for the intermediate conductive layer may be chosen from any suitable conductive material known in the art. The choice of the material may be determined based on, for example, the particular zwitterionic molecule, the particular material for the first electrode, and/or the particular fabrication technique used for making the device.

[0041] The at least one layer **120** of zwitterionic molecules may include any zwitterionic molecules known in the art as described herein. In some embodiments, the at least one layer **120** of zwitterionic molecules may be a self-assembled monolayer. In various

embodiments of the device **200** for harnessing energy, the at least one layer **120** of zwitterionic molecules may be configured to rectify the output from the at least one layer of antennas **240**. Various embodiments of the first electrode **110** and the second electrode **130** are described herein. In some embodiments, the device **200** may further include an electric energy storage device, such as a battery or a supercapacitor, arranged in electrical contact with the second electrode **130**.

[0042] Further embodiments of the present disclosure may be directed to systems for harnessing light energy. Figure 4 depicts a schematic diagram of an illustrative system for harnessing light energy in accordance with some embodiments. In some embodiments, a system **400** for harnessing light energy may include a first device **410** configured to convert light energy into a high-frequency electric signal, a second device **420** operably coupled to the first device **410** and configured to rectify the high-frequency electric signal emanating from the first device **410**, and a third device **430** operably coupled to the second device **420** and configured to store energy.

[0043] In some embodiments, the first device **410** may include at least one layer of antennas. The antennas may be of any kind known in the art such as, for example, dipoles, monopoles, extra short dipoles, linear model, Yagi-Uda arrays, log-periodic arrays, collinear arrays, or a combination thereof. In some embodiments, the antennas may be $\frac{1}{2}$ -wavelength dipoles, $\frac{1}{4}$ -wavelength dipoles, or integer multiples of $\frac{1}{2}$ -wavelength dipoles. In certain embodiments, the antennas may be nano-antennas **300**, as described herein, having resonant frequency in a range of about 300 GHz to about 10 PHz. In various embodiments, the nano-antennas may include a porous membrane, a plurality of nanowires disposed in the porous membrane, and a monolayer of nanospheres having substantially the same diameter as the nanowires, electrically coupled in series with the plurality of nanowires. In some

embodiments, the porous membrane may be made of, for example, alumina, silicon, silicon dioxide, polymethyl methacrylate, and the like.

[0044] In certain embodiments, the nanowires and/or the nanospheres may have a diameter in a range of about 5 nm to about 500 nm. The nanowires may include any conductive material known in the art such as, for example, a metal, a metal alloy, a semi-metal, a conductor, a dielectric, a conducting polymer, a doped semiconductor, a doped metal oxide, a carbon allotrope, a DNA molecule, a biomolecule, and any combination thereof. The nanospheres may include any dielectric material known in the art such as, for example, polymers, glasses, silica, carbohydrates, lignin, combinations thereof, and the like, or any conductive materials known in the art such as, for example, metals, metal alloys, doped semiconductors, conductive polymers, and the like, or any combinations thereof.

[0045] In certain embodiments, the second device **420** may include a device having a first electrode **110**, at least one layer **120** of zwitterionic molecules, and a second electrode **130**. The at least one layer **120** of zwitterionic molecules is arranged in electrical contact with the first electrode **110** and the second electrode **130** such that the at least one layer **120** of zwitterionic molecules provides a selectively activated electrical conduction path between the first electrode **110** and the second electrode **130**. In various embodiments, the first electrode **110** and/or the second electrode **130** may include any suitable material known in the art such as, for example, a metal, a metal alloy, a semi-metal, a conductor, a conducting polymer, a doped semiconductor, a doped metal oxide, a carbon allotrope, and the like, or any combination thereof. In some embodiments, the zwitterionic molecules may have any configuration known in the art such as, for example, donor-(π -bridge)-acceptor, donor-(σ -bridge)-acceptor, or any combination thereof. In certain embodiments, the zwitterionic molecule may be C₁₆H₃₃Q-3CNQ.

[0046] In various embodiments, the third device **430** may include any energy storage device configured to store electrical energy such as, for example, a battery, a capacitor, a supercapacitor, a superconducting magnetic energy storage, a fuel cell, and the like, or any combination thereof.

[0047] Embodiments are further directed to methods of rectifying a high-frequency signal. A method of rectifying a high-frequency signal may, in some embodiments, include transmitting the high-frequency signal through at least one layer of zwitterionic molecules. The method may be used for rectifying any high-frequency signal. Thus, the method may include transmitting a signal that is an output of an array of antennas. In some embodiments, the high-frequency signal may be an output of an array of antennas. In various embodiments, the high-frequency signal may be transmitted at a frequency in a range of about 300 GHz to about 10 PHz.

[0048] Any zwitterionic molecules known in the art may be used for rectifying the high-frequency signal. In various embodiments, molecules of the layer of zwitterionic molecules may have a donor-(σ)-acceptor configuration, where “ σ ” is a covalent bridge (shared s-electrons) having a low electron mobility linking the donor and acceptor moieties. In such molecules, the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) for the donor moiety have higher energies than the HOMO and the LUMO for the acceptor moiety and are highly localized on the respective moieties. As such, a small positive voltage (acceptor as cathode) or a forward bias may provide sufficient energy for the electrons to tunnel across the σ -bridge from the donor to the acceptor. Because a negative voltage (acceptor as anode) or reverse bias would add electrons to the acceptor LUMO and deplete electrons from the donor HOMO thereby, raising the energy of acceptor LUMO higher than the donor HOMO, a significantly higher voltage may

be needed for the electrons to tunnel across the σ -bridge from the acceptor to the donor. This provides for molecular rectification.

[0049] In some embodiments, the signal may be transmitted through molecules of the layer of zwitterionic molecules having a donor-(π)-acceptor configuration. In such a configuration, “ π ” may indicate a covalent bridge (shared p-electrons) having high electron mobility linking the donor and acceptor moieties. Thus, the HOMO and LUMO for the donor and acceptor moieties may be strongly delocalized over the entire molecule. Accordingly, the molecule may have a large dipole moment. When electrodes are brought in contact with such a molecule, the HOMO and LUMO for the donor and the acceptor become more localized. As a result, charges may be induced on the electrodes. The electrode near the acceptor may get a negative charge and the electrode near the donor may get a positive charge. This may result in a build-up of a small potential difference (barrier potential) between the two electrodes. As such, if a forward external bias greater than this potential difference is applied, electron transport from donor to acceptor occurs. In contrast, applying a reverse external bias increases the barrier potential, thereby limiting the electron transport in the reverse direction.

[0050] In some embodiments, the signal may be transmitted through at least one layer of zwitterionic molecules that includes a self-assembled monolayer of zwitterionic molecules. Various examples of suitable zwitterionic molecules that may be used for rectifying a high-frequency signal include, but are not limited to, hexadecylquinolinium tricyanoquinodimethanide ($C_{16}H_{33}-\gamma Q_3CNQ$), dimethylanilinoaza[C]-fullerene, N-3- γ -Pyrodiylaza[60]fulleroid ($C_{60}NPy$), 29-amino-4-ethynylphenyl-49-ethynylphenyl-59-nitro-1-benzenethiol, 2,6-dibutylaminophenylvinyl-1-butylpyridinium iodide, fullerene-bis-[4-diphenylamino-4''-(N-ethyl-N-2''-ethyl)-amino-1,4-diphenyl-1,3-butadiene] malonate, N-(10-nonadecyl)-N-(2-ferrocenylethyl)pyrenyle-3,4,9,10-bis (dicarboxyimide), 4,5-dipentyl-

50-methyltetra-thiafulvalen-40-methyloxy-2,4,5-trinitro-9-dicyanomethylenefluorene-7-(3-sulfonylpropionate), and the like.

[0051] Further embodiments may be directed to methods for harnessing light energy. In some embodiments, a method for harnessing light energy may include converting light energy into a high-frequency electric signal, rectifying the high-frequency electric signal to form a rectified signal having an energy and storing the energy of the rectified signal in an energy storage device.

[0052] Light energy can be converted into a high-frequency electric signal using any device known in the art. In some embodiments, converting the light energy into a high-frequency electric signal may include collecting the light energy using at least one array of antennas. In various embodiments, the antennas collecting the light energy may be configured to have a resonance frequency in a range of about 300 GHz to about 10 PHz. The antennas collecting the light energy may be of any kind known in the art such as, for example, dipoles, monopoles, extra short dipoles, linear model, Yagi-Uda arrays, log-periodic arrays, collinear arrays, or a combination thereof. In some embodiments, the antennas collecting the light energy may be $\frac{1}{2}$ -wavelength dipoles, $\frac{1}{4}$ -wavelength dipoles, or integer multiples of $\frac{1}{2}$ -wavelength dipoles.

[0053] In certain embodiments, the antennas collecting the light energy may include an array of nano-antennas. Various embodiments of nano-antennas that collect light energy are described herein. In some embodiments, the nano-antennas collecting the light energy may include conducting nanowires. In some embodiments, the nano-antennas collecting the light energy may include a porous membrane, a plurality of nanowires disposed in the porous membrane, and a monolayer of nanospheres having substantially the same diameter as the nanowires and electrically in series with the nanowires. In certain embodiments, the nano-antennas collecting the light energy may be substantially transparent

or translucent to infrared and/or visible light. In various embodiments, the nano-antennas collecting the light energy may include a metal, a metal alloy, a semi-metal, a conductor, a dielectric, a conducting polymer, a doped semiconductor, a doped metal oxide, a carbon allotrope, a biomolecule, a DNA molecule, and the like, or any combination thereof.

[0054] In some embodiments, rectifying the high-frequency signal may include transmitting the high-frequency signal through at least one layer of zwitterionic molecules. The at least one layer of zwitterionic molecules through which the signal is transmitted, in some embodiments, may include any zwitterionic molecules known in the art such as, for example, molecules having a configuration of donor-(σ -bridge)-acceptor or molecules having a configuration of donor-(π -bridge)-acceptor. Various examples of zwitterionic molecules are described herein.

[0055] In some embodiments, storing the energy includes storing the energy associated with the rectified high-frequency electric signal in a device such as, for example, a battery, a supercapacitor, a capacitor, a superconducting magnetic energy storage device, a fuel cell, and the like, or combinations thereof.

[0056] Still further embodiments may be directed to methods of making a device for rectifying a high-frequency signal. In some embodiments, a method of making a device for rectifying a high-frequency signal may include disposing at least one layer of zwitterionic molecules on a first electrode and contacting a second electrode with the at least one layer of zwitterionic molecules such that the at least one layer of zwitterionic molecules provides a selectively activated electrical conduction path between the first electrode and the second electrode.

[0057] In some embodiments, the at least one layer of zwitterionic molecules disposed on the first electrode and/or contacted with the second electrode may include a monolayer of zwitterionic molecules. Any method known in the art may be used for

disposing the at least one layer of zwitterionic molecules on the first electrode. In certain embodiments, the at least one layer of zwitterionic molecules may be disposed on the first electrode by electrostatic self-assembly. In some embodiments, the at least one layer of zwitterionic molecules may be disposed on the first electrode by covalent self-assembly such as, for example, a Langmuir-Blodgett film. Various examples of suitable zwitterionic molecules are described herein.

[0058] In various embodiments, contacting a second electrode on the at least one layer of zwitterionic molecules may include depositing a suitable material on the at least one layer of zwitterionic molecules. In certain embodiments, depositing a suitable material may include physical vapor deposition, thermal evaporation, electro-deposition, and the like, or combinations thereof.

[0059] Still further embodiments may be directed to methods of making a device for harnessing energy. In various embodiments, methods of making a device for harnessing energy may include disposing an array of antennas in a porous membrane, disposing a first electrode on the porous membrane such that a first side of the electrode is in electrical contact with the array of antennas, disposing at least one layer of zwitterionic molecules on the first electrode such that the at least one layer of zwitterionic molecules is in electrical contact with a second side of the first electrode, and contacting a second electrode with the at least one layer of zwitterionic molecules such that the at least one layer of zwitterionic molecules provides a selectively activated electrical path between the first electrode and the second electrode.

[0060] In some embodiments, disposing an array of antennas in a porous membrane may include depositing a plurality of nanowires in the porous membrane by physical vapor deposition. In some embodiments, the plurality of nanowires may be formed in a thin film by using photolithography followed by etching away the thin film. In some

embodiments, the nanowires may be formed by self-assembly. In various embodiments, the plurality of nanowires may be deposited using, for example, chemical vapor deposition, pulsed laser deposition, and the like, or combinations thereof. In some embodiments, disposing an array of antennas may further include disposing a monolayer of nanospheres having substantially the same diameter as the nanowires electrically in series with the plurality of nanowires. Various embodiments of the porous membrane, the plurality of nanowires, and the nanospheres are described herein.

[0061] The first electrode may be disposed on the porous membrane by any method known in the art such as, for example, chemical vapor deposition, thermal evaporation, spray pyrolysis, pulsed laser deposition, electron-beam assisted evaporation, electrodeposition, spin-coating, dip-coating, and the like, or any combination thereof.

[0062] In some embodiments, disposing the at least one layer of zwitterionic molecules may include forming a monolayer of zwitterionic molecules using, for example, electrostatic self-assembly, covalent self-assembly, Langmuir-Blodgett self-assembly, spray-coating, dip-coating, and the like, or any combination thereof. Various embodiments of suitable zwitterionic molecules are described herein. It is to be understood that the particular method for disposing the at least one layer of zwitterionic molecules will depend on the particular choice of the zwitterionic molecules and the material of the first electrode.

[0063] In some embodiments, contacting the second electrode may include depositing a suitable material on the at least one layer of zwitterionic molecules. In certain embodiments, the second electrode may be deposited using, for example, electrodeposition, thermal evaporation, chemical vapor deposition, spray-coating, electrospraying, dip-coating, and the like, or any combination thereof. Materials suitable for the second electrode are described herein. In some embodiments contacting the second electrode may include forming a junction between the first electrode and the second electrode.

EXAMPLESExample 1: High-frequency rectifier.

[0064] A thin layer of gold may be deposited on a dielectric substrate by thermal evaporation. The gold layer may be arranged to be operable as a first electrode. A monolayer of C16H33Q-3CNQ may be deposited on the gold layer using a Langmuir-Blodgett self-assembly process. A second electrode of gold may be deposited on top of the C16H33Q-3CNQ layer using low temperature thermal evaporation to form the device for rectifying high-frequency signals. A high-frequency signal applied across the two electrodes can be rectified by the monolayer of C16H33Q-3CNQ.

Example 2: Solar energy harnessing device.

[0065] Monopole nano-antennas may be fabricated by electrodepositing gold on a 200 nm thick porous alumina membrane with a pore size in a range of about 10 nm to about 50 nm. The gold material fills in the pores of the alumina membrane and acts a nanowire having an aspect ratio in a range of about 20:1 to about 4:1. A monolayer nanospheres of PMMA with diameter in a range of about 10 nm to about 50 nm may be deposited on top of the gold-filled alumina membrane by disposing a suitably diluted suspension containing PMMA nanospheres on the alumina surface, forming an array of monopole nano-antennas. The high-frequency rectifier device of Example 1 may be fabricated on top of the array of monopole nano-antennas such that the monolayer of PMMA nanospheres are suitable as the dielectric surface on which the first gold electrode is deposited.

[0066] Nano-antennas of different lengths have different resonant frequencies of the infrared and visible spectrum. When the array of nano-antennas is exposed to sunlight, light of various frequencies corresponding to the various resonant frequencies is converted into electrical signals of corresponding frequencies (in a range from about 10 THz to about 80 THz for the particular pore size). The electrical signals may be rectified by the layer of

zwitterionic molecules (C16H33Q-3CNQ) to produce a rectified signal. The second electrode of the device can be coupled to a battery that stores the energy associated with the rectified signal.

[0067] The present disclosure is not to be limited in terms of the particular embodiments described in this application, which are intended as illustrations of various aspects. Many modifications and variations can be made without departing from its spirit and scope, as will be apparent to those skilled in the art. Functionally equivalent methods and apparatuses within the scope of the disclosure, in addition to those enumerated herein, will be apparent to those skilled in the art from the foregoing descriptions. Such modifications and variations are intended to fall within the scope of the appended claims. The present disclosure is to be limited only by the terms of the appended claims, along with the full scope of equivalents to which such claims are entitled. It is to be understood that this disclosure is not limited to particular methods, reagents, compounds, compositions or biological systems, which can, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

[0068] With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity.

[0069] It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as “open” terms (e.g., the term “including” should be interpreted as “including but not limited to,” the term “having” should be interpreted as “having at least,” the term “includes” should be interpreted as “includes but is not limited to,” etc.). It will be

further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to embodiments containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should be interpreted to mean "at least one" or "one or more"); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should be interpreted to mean at least the recited number (e.g., the bare recitation of "two recitations," without other modifiers, means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to "at least one of A, B, and C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, and C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, or C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase

presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms. For example, the phrase “A or B” will be understood to include the possibilities of “A” or “B” or “A and B.”

[0070] In addition, where features or aspects of the disclosure are described in terms of Markush groups, those skilled in the art will recognize that the disclosure is also thereby described in terms of any individual member or subgroup of members of the Markush group.

[0071] As will be understood by one skilled in the art, for any and all purposes, such as in terms of providing a written description, all ranges disclosed herein also encompass any and all possible subranges and combinations of subranges thereof. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, tenths, etc. As a non-limiting example, each range discussed herein can be readily broken down into a lower third, middle third and upper third, etc. As will also be understood by one skilled in the art all language such as “up to,” “at least,” and the like include the number recited and refer to ranges which can be subsequently broken down into subranges as discussed above. Finally, as will be understood by one skilled in the art, a range includes each individual member. Thus, for example, a group having 1-3 cells refers to groups having 1, 2, or 3 cells. Similarly, a group having 1-5 cells refers to groups having 1, 2, 3, 4, or 5 cells, and so forth.

[0072] Various of the above-disclosed and other features and functions, or alternatives thereof, may be combined into many other different systems or applications. Various presently unforeseen or unanticipated alternatives, modifications, variations or improvements therein may be subsequently made by those skilled in the art, each of which is also intended to be encompassed by the disclosed embodiments.

CLAIMS

What is claimed is:

1. A device for rectifying a high-frequency signal, the device comprising:
a first electrode;
a second electrode; and
at least one layer of zwitterionic molecules arranged in electrical contact with the first electrode and the second electrode such that the at least one layer of zwitterionic molecules provides a selectively activated electrical conduction path between the first electrode and the second electrode.
2. The device of claim 1, wherein the first electrode comprises one or more of a metal, a metal alloy, a semi-metal, a conductor, a conducting polymer, a doped semiconductor, a doped metal oxide, and a carbon allotrope.
3. The device of claim 1, wherein the second electrode comprises one or more of a metal, a metal alloy, a semi-metal, a conductor, a dielectric, a conducting polymer, a doped semiconductor, a doped metal oxide, and a carbon allotrope.
4. The device of claim 1, wherein the zwitterionic molecules have a donor-(π -bridge)-acceptor configuration that is operationally effective to transport electrons from the donor to the acceptor responsive to application of a forward external bias greater than a barrier potential.
5. The device of claim 1, wherein the at least one layer of zwitterionic molecules comprises a self-assembled monolayer.

6. The device of claim 1, wherein the zwitterionic molecules comprise one of hexadecylquinolinium tricyanoquinodimethanide ($C_{16}H_{33}-\gamma Q_3CNQ$), 2,6-dibutylaminophenylvinyl-1-butylpyridinium iodide, dimethylanilinoaza[C]-fullerene, fullerene-bis-[4-diphenylamino-4''-(N-ethyl-N-2''-ethyl)-amino-1,4-diphenyl-1,3-butadiene] malonate, N-3- γ -Pyrodlaza[60]fulleroid ($C_{60}NPy$), N-(10-nonadecyl)-N-(2-ferrocenylethyl)pyrenyle-3,4,9,10-bis (dicarboxyimide), 4,5-dipentyl-50-methyltetra-thiafulvalen-40-methyloxy2,4,5-trinitro-9-dicyanomethylene fluorene-7-(3-sulfonylpropionate), and 29-amino-4-ethynylphenyl-49-ethynylphenyl-59-nitro-1-benzenethiol.
7. A device for harnessing energy, the device comprising:
- a first electrode having a first side and a second side;
 - a second electrode;
 - at least one layer of antennas arranged in electrical contact with the first side of the first electrode; and
 - at least one layer of zwitterionic molecules arranged in electrical contact with the second side of the first electrode and the second electrode such that the at least one layer of zwitterionic molecules provides a selectively activated electrical conduction path between the first electrode and the second electrode.
8. The device of claim 7, wherein the energy comprises light.
9. The device of claim 7, wherein the antennas are configured to resonate at a frequency in a range of about 300 gigahertz (GHz) to about 10 petahertz (PHz).
10. The device of claim 7, wherein the antennas have a geometry of a dipole, a monopole, a Yagi-Uda array, a log-periodic array, a collinear array, an extra short dipole, or any combination thereof.

11. The device of claim 7, wherein the at least one layer of antennas comprises an array of nano-antennas.
12. The device of claim 11, wherein the nano-antennas comprise conducting nanowires.
13. The device of claim 11, wherein the nano-antennas comprise:
 - a porous membrane;
 - a plurality of nanowires disposed in the porous membrane, wherein each nanowire has a diameter; and
 - a monolayer of nanospheres electrically in series with the plurality of nanowires, wherein the nanospheres have substantially the same diameter as the nanowires.
14. The device of claim 11, wherein the nano-antennas are visibly transparent or visibly translucent.
15. The device of claim 11, wherein the nano-antennas comprise a metal, a metal alloy, a semi-metal, a conductor, a dielectric, a conducting polymer, a doped semiconductor, a doped metal oxide, a carbon allotrope, a DNA molecule, a biomolecule, or any combination thereof.
16. The device of claim 7, further comprising at least one intermediate conductive layer forming an electrical contact between the second side of the first electrode and the at least one layer of zwitterionic molecules.
17. The device of claim 7, wherein the zwitterionic molecules have a donor-(π -bridge)-acceptor configuration that is operationally effective to transport electrons from the donor to the acceptor responsive to application of a forward external bias greater than a barrier potential.

18. The device of claim 7, wherein the at least one layer of zwitterionic molecules comprises a self-assembled monolayer.

19. The device of claim 7, wherein the at least one layer of zwitterionic molecules comprises one of hexadecylquinolinium tricyanoquinodimethanide (C₁₆H₃₃-γQ₃CNQ), 2,6-dibutylaminophenylvinyl-1-butylpyridinium iodide, dimethylanilinoaza[C]-fullerene, fullerene-bis-[4-diphenylamino-4''-(N-ethyl-N-2''-ethyl)-amino-1,4-diphenyl-1,3-butadiene] malonate, N-3-γ-Pyrodylaza[60]fulleroid (C₆₀NPy), N-(10-nonadecyl)-N-(2-ferrocenylethyl)pyrenyle-3,4,9,10-bis (dicarboxyimide), 4,5-dipentyl-50-methyltetra-thiafulvalen-40-methyloxy-2,4,5-trinitro-9-dicyanomethylenefluorene-7-(3-sulfonylpropionate), and 29-amino-4-ethynylphenyl-49-ethynylphenyl-59-nitro-1-benzenethiol.

20. The device of claim 7, wherein the at least one layer of zwitterionic molecules is configured to rectify an output from the at least one layer of antennas.

21. The device of claim 7, wherein one or more of the first electrode and the second electrode comprise one or more of a metal, a metal alloy, a semi-metal, a conductor, a conducting polymer, a doped semiconductor, a doped metal oxide, and a carbon allotrope.

22. The device of claim 7, further comprising an electric energy storage device in electrical contact with the second electrode.

23. A system for harnessing light energy, the system comprising:

a first device configured to convert light energy into a high-frequency electric signal, wherein the first device comprises at least one layer of nano-antennas;

a second device operably coupled to the first device and configured to rectify the high-frequency electric signal emanating from the first device; and

a third device operably coupled to the second device and configured to store energy.

24. The system of claim 23, wherein the nano-antennas are configured to resonate at a frequency in a range of about 300 gigahertz (GHz) to about 10 petahertz (PHz).

25. The system of claim 23, wherein the nano-antennas have a geometry of a dipole, a monopole, a Yagi-Uda array, a log-periodic array, a collinear array, an extra short dipole, or any combination thereof.

26. The system of claim 23, wherein the at least one layer of nano-antennas comprises an array of nano-antennas.

27. The system of claim 23, wherein the nano-antennas comprise conducting nanowires.

28. The system of claim 23, wherein the nano-antennas comprise:

a porous membrane;

a plurality of nanowires disposed in the porous membrane, wherein each nanowire has a diameter; and

a monolayer of nanospheres electrically in series with the plurality of nanowires, wherein the nanospheres have substantially the same diameter as the nanowires.

29. The system of claim 23, wherein the nano-antennas are visibly transparent or visibly translucent.

30. The system of claim 23, wherein the nano-antennas comprise a metal, a metal alloy, a semi-metal, a conductor, a dielectric, a conducting polymer, a doped semiconductor, a doped metal oxide, a carbon allotrope, a DNA molecule, a biomolecule, or any combination thereof.

31. The system of claim 23, wherein the second device comprises:

a first electrode;

at least one layer of zwitterionic molecules, the at least one layer having a first side and a second side; and

a second electrode,

wherein the at least one layer of zwitterionic molecules is arranged in electrical contact with the first electrode and the second electrode such that the at least one layer of zwitterionic molecules provides a selectively activated electrical conduction path between the first electrode and the second electrode.

32. The system of claim 31, further comprising at least one intermediate conductive layer electrically coupling between the first device and the second device.

33. The system of claim 31, wherein the at least one layer of zwitterionic molecules is a self-assembled monolayer.

34. The system of claim 31, wherein the zwitterionic molecules have a donor-(π -bridge)-acceptor configuration that is operationally effective to transport electrons from the donor to the acceptor upon application of a forward external bias greater than a barrier potential.

35. The system of claim 31, wherein the zwitterionic molecules comprise one of hexadecylquinolinium tricyanoquinodimethanide ($C_{16}H_{33}-\gamma Q_3CNQ$), 2,6-dibutylaminophenylvinyl-1-butylpyridinium iodide, dimethylanilinoaza[C]-fullerene, fullerene-bis-[4-diphenylamino-4''-(N-ethyl-N-2''-ethyl)-amino-1,4-diphenyl-1,3-butadiene] malonate, N-3- γ -Pyrolyaza[60]fulleroid ($C_{60}NPy$), N-(10-nonadecyl)-N-(2-ferrocenylethyl)pyrenyle-3,4,9,10-bis (dicarboxyimide), 4,5-dipentyl-50-methyltetra-thiafulvalen-40-methyloxy-2,4,5-trinitro-9-dicyanomethylenefluorene-7-(3-sulfonylpropionate), and 29-amino-4-ethynylphenyl-49-ethynylphenyl-59-nitro-1-benzenethiol.

36. The system of claim 31, wherein one or more of the first electrode and the second electrode comprises one or more of a metal, a metal alloy, a semi-metal, a conductor, a conducting polymer, a doped semiconductor, a doped metal oxide, and a carbon allotrope.
37. The system of claim 23, wherein the third device comprises one or more of a battery, a capacitor, a supercapacitor, a superconducting magnetic energy storage, and a fuel cell.
38. A method of rectifying a high-frequency signal, the method comprising:
transmitting the high-frequency signal through at least one layer of zwitterionic molecules.
39. The method of claim 38, wherein transmitting the high-frequency signal comprises transmitting a high-frequency signal that is an output of an array of antennas.
40. The method of claim 38, wherein transmitting the high-frequency signal comprises transmitting the high-frequency signal at a frequency in a range of about 300 gigahertz (GHz) to about 10 petahertz (PHz).
41. The method of claim 38, wherein transmitting the high-frequency signal comprises transmitting the high-frequency signal through at least one layer of zwitterionic molecules having a donor-(π -bridge)-acceptor configuration.
42. The method of claim 41, wherein transmitting the high frequency signal comprises applying a forward external bias greater than a barrier potential to cause electron transport from the donor to the acceptor.
43. The method of claim 41, wherein transmitting the high-frequency signal comprises applying a reverse external bias less than a barrier potential to limit electron transport from the acceptor to the donor.

44. The method of claim 38, wherein transmitting the high-frequency signal comprises transmitting the high-frequency signal through a self-assembled monolayer of the zwitterionic molecules.

45. The method of claim 38, wherein transmitting the high-frequency signal comprises transmitting the high-frequency signal through at least one layer of zwitterionic molecules comprising one of hexadecylquinolinium tricyanoquinodimethanide (C₁₆H₃₃-γQ₃CNQ), 2,6-dibutylaminophenylvinyl-1-butylpyridinium iodide, dimethylanilinoaza[C]-fullerene, fullerene-bis-[4-diphenylamino-4''-(N-ethyl-N-2''-ethyl)-amino-1,4-diphenyl-1,3-butadiene] malonate, N-3-γ-Pyrodylaza[60]fulleroid (C₆₀NPy), N-(10-nonadecyl)-N-(2-ferrocenylethyl)pyrenyle-3,4,9,10-bis (dicarboxyimide), 4,5-dipentyl-50-methyltetra-thiafulvalen-40-methyloxy-2,4,5-trinitro-9-dicyanomethylenefluorene-7-(3-sulfonylpropionate), and 29-amino-4-ethynylphenyl-49-ethynylphenyl-59-nitro-1-benzenethiol.

46. A method for harnessing light energy, the method comprising:

converting light energy into a high-frequency electric signal using at least one array of antennas that are configured to have a resonance frequency in a range of about 300 gigahertz (GHz) to about 10 petahertz (PHz);

rectifying the high-frequency electric signal to form a rectified signal having an energy; and

storing the energy of the rectified signal in an energy storage device.

47. The method of claim 46, wherein converting light energy into a high-frequency electric signal comprises collecting the light energy using at least one array of antennas having a geometry of a dipole, a monopole, a Yagi-Uda array, a log-periodic array, a collinear array, an extra short dipole, or any combination thereof.

48. The method of claim 46, wherein converting light energy into a high-frequency electric signal comprises collecting the light energy using an array of nano-antennas.

49. The method of claim 46, wherein converting light energy into a high-frequency electric signal comprises collecting the light energy using at least one array of nano-antennas comprising conducting nanowires.

50. The method of claim 46, wherein converting light energy into a high-frequency electric signal comprises collecting the light energy using at least one array of nano-antennas comprising:

a porous membrane;

a plurality of nanowires disposed in the porous membrane, wherein each nanowire has a diameter; and

a monolayer of nanospheres electrically in series with the plurality of nanowires, wherein the nanospheres have substantially the same diameter as the nanowires.

51. The method of claim 46, wherein converting light energy into a high-frequency electric signal comprises collecting the light energy using at least one array of nano-antennas that are visibly transparent or visibly translucent.

52. The method of claim 46, wherein converting light energy into a high-frequency electric signal comprises collecting the light energy using at least one array of nano-antennas comprising a metal, a metal alloy, a semi-metal, a conductor, a dielectric, a conducting polymer, a doped semiconductor, a doped metal oxide, a carbon allotrope, a DNA molecule, a biomolecule, or any combination thereof.

53. The method of claim 46, wherein rectifying the high-frequency signal comprises transmitting the high-frequency signal through at least one layer of zwitterionic molecules.

54. The method of claim 46, wherein rectifying the high-frequency signal comprises transmitting the high-frequency signal through at least one layer of zwitterionic molecules having a donor-(π -bridge)-acceptor configuration.

55. The method of claim 54, wherein transmitting the high frequency signal comprises applying a forward external bias greater than a barrier potential to cause electron transport from the donor to the acceptor.

56. The method of claim 54, wherein transmitting the high-frequency signal comprises applying a reverse external bias less than a barrier potential to limit electron transport from the acceptor to the donor.

57. The method of claim 46, wherein rectifying the high-frequency signal comprises transmitting the high-frequency signal through a self-assembled monolayer of zwitterionic molecules.

58. The method of claim 46, wherein rectifying the high-frequency signal comprises transmitting the high-frequency signal through at least one layer of zwitterionic molecules comprising one of hexadecylquinolinium tricyanoquinodimethanide (C₁₆H₃₃- γ Q₃CNQ), 2,6-dibutylaminophenylvinyl-1-butylpyridinium iodide, dimethylanilinoaza[C]-fullerene, fullerene-bis-[4-diphenylamino-4''-(N-ethyl-N-2''-ethyl)-amino-1,4-diphenyl-1,3-butadiene] malonate, N-3- γ -Pyrodlaza[60]fulleroid (C₆₀NPy), N-(10-nonadecyl)-N-(2-ferrocenylethyl)pyrenyle-3,4,9,10-bis (dicarboxyimide), 4,5-dipentyl-50-methyltetra-thiafulvalen-40-methyloxy-2,4,5-trinitro-9-dicyanomethylenefluorene-7-(3-sulfonylpropionate), and 29-amino-4-ethynylphenyl-49-ethynylphenyl-59-nitro-1-benzenethiol.

59. The method of claim 46, wherein storing the energy of the rectified signal comprises storing the energy in one or more of a battery, a capacitor, a supercapacitor, a superconducting magnetic energy storage, and a fuel cell.

60. A method of making a device for rectifying a high-frequency signal, the method comprising:

disposing at least one layer of zwitterionic molecules on a first electrode; and

contacting a second electrode with the at least one layer of zwitterionic molecules such that the at least one layer of zwitterionic molecules provides a selectively activated electrical conduction path between the first electrode and the second electrode.

61. The method of claim 60, wherein contacting the second electrode with the at least one layer of zwitterionic molecules comprises contacting the second electrode with a monolayer of zwitterionic molecules.

62. The method of claim 60, wherein disposing the at least one layer of zwitterionic molecules on the first electrode comprises disposing a monolayer of zwitterionic molecules on the first electrode.

63. The method of claim 60, wherein disposing at least one layer of zwitterionic molecules comprises forming a monolayer of zwitterionic molecules by electrostatic self-assembly.

64. The method of claim 60, wherein disposing at least one layer of zwitterionic molecules comprises forming a monolayer of zwitterionic molecules by covalent self-assembly.

65. The method of claim 60, wherein contacting the second electrode with the at least one layer of zwitterionic molecules comprises contacting the second electrode with zwitterionic molecules having a donor-(π -bridge)-acceptor configuration.
66. The method of claim 60, wherein contacting a second electrode comprises depositing an electrode on the at least one layer of zwitterionic molecules.
67. The method of claim 60, wherein contacting a second electrode comprises forming a junction between the first electrode and the second electrode.
68. The method of claim 60, wherein disposing the at least one layer of zwitterionic molecules on the first electrode comprises disposing the at least one layer of zwitterionic molecules on a first electrode comprising one or more of a metal, a metal alloy, a semi-metal, a conductor, a conducting polymer, a doped semiconductor, a doped metal oxide, and a carbon allotrope.
69. The method of claim 60, wherein contacting the second electrode with the at least one layer of zwitterionic molecules comprises contacting a second electrode comprising one or more of a metal, a metal alloy, a semi-metal, a conductor, a conducting polymer, a doped semiconductor, a doped metal oxide, and a carbon allotrope.
70. A method of making a device for harnessing energy, the method comprising:
- disposing an array of antennas in a porous membrane;
 - disposing a first electrode having a first side and a second side on the porous membrane such that the first side is in electrical contact with the array of antennas;
 - disposing at least one layer of zwitterionic molecules on the first electrode such that the at least one layer of zwitterionic molecules is in electrical contact with the second side of the first electrode; and

contacting a second electrode with the at least one layer of zwitterionic molecules such that the at least one layer of zwitterionic molecules provides a selectively activated electrical conduction path between the first electrode and the second electrode.

71. The method of claim 70, wherein disposing an array of antennas in a porous membrane comprises depositing a plurality of nanowires having a diameter in the porous membrane.

72. The method of claim 71, further comprising placing a monolayer of nanospheres electrically in series with the plurality of nanowires, wherein the nanospheres have substantially the same diameter as the nanowires.

73. The method of claim 70, wherein disposing an array of antennas in a porous membrane comprises depositing a plurality of nanowires comprising a metal, a metal alloy, a semi-metal, a conductor, a conducting polymer, a doped semiconductor, a doped metal oxide, a carbon allotrope, a DNA molecule, a biomolecule, or any combination thereof in the porous membrane.

74. The method of claim 70, wherein disposing the at least one layer of zwitterionic molecules on the first electrode comprises disposing a monolayer of zwitterionic molecules on the first electrode.

75. The method of claim 70, wherein contacting the second electrode with the at least one layer of zwitterionic molecules comprises contacting the second electrode with a monolayer of zwitterionic molecules.

76. The method of claim 70, wherein disposing at least one layer of zwitterionic molecules comprises forming a monolayer of zwitterionic molecules by electrostatic self-assembly.

77. The method of claim 70, wherein disposing at least one layer of zwitterionic molecules comprises forming a monolayer of zwitterionic molecules by covalent self-assembly.
78. The method of claim 70, wherein disposing the at least one layer of zwitterionic molecules on the first electrode comprises disposing at least one layer of zwitterionic molecules having a donor-(π -bridge)-acceptor configuration.
79. The method of claim 70, wherein contacting the second electrode with the at least one layer of zwitterionic molecules comprises contacting the second electrode with at least one layer of zwitterionic molecules having a donor-(π -bridge)-acceptor configuration.
80. The method of claim 70, wherein contacting a second electrode comprises depositing a conducting electrode on the at least one layer of zwitterionic molecules.
81. The method of claim 70, wherein contacting a second electrode comprises forming a junction between the first electrode and the second electrode.
82. The method of claim 70, wherein disposing the at least one layer of zwitterionic molecules on the first electrode comprises disposing at least one layer of zwitterionic molecules on a first electrode comprising one or more of a metal, a metal alloy, a semi-metal, a conductor, a conducting polymer, a doped semiconductor, a doped metal oxide, and a carbon allotrope.
83. The method of claim 70, wherein contacting a second electrode with the at least one layer of zwitterionic molecules comprises contacting a second electrode comprising one or more of a metal, a metal alloy, a semi-metal, a conductor, a conducting polymer, a doped semiconductor, a doped metal oxide, and a carbon allotrope.

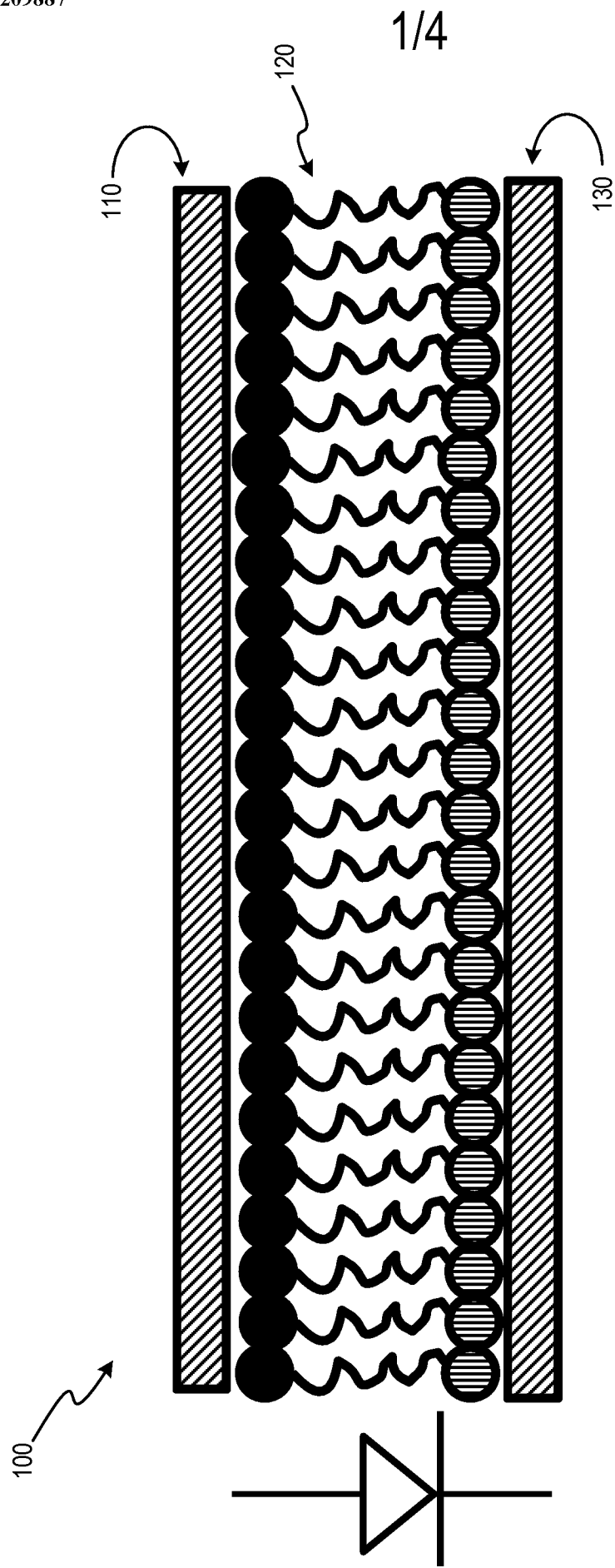


FIG. 1

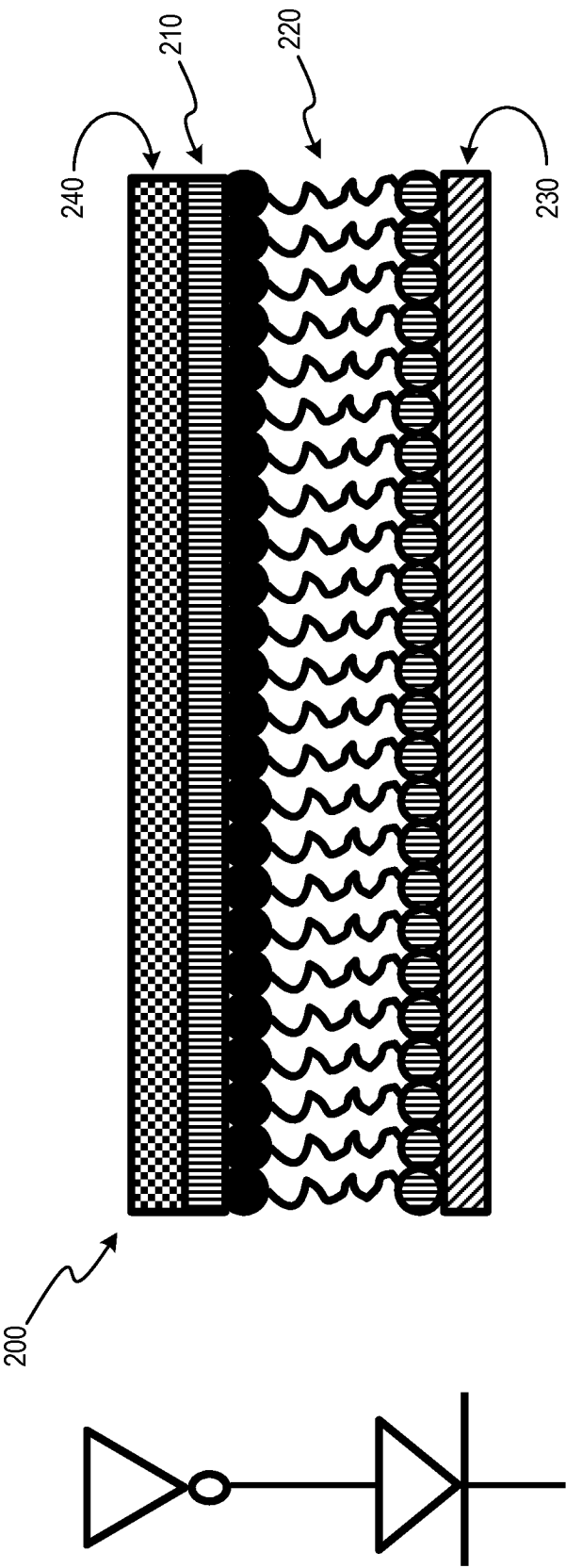


FIG. 2

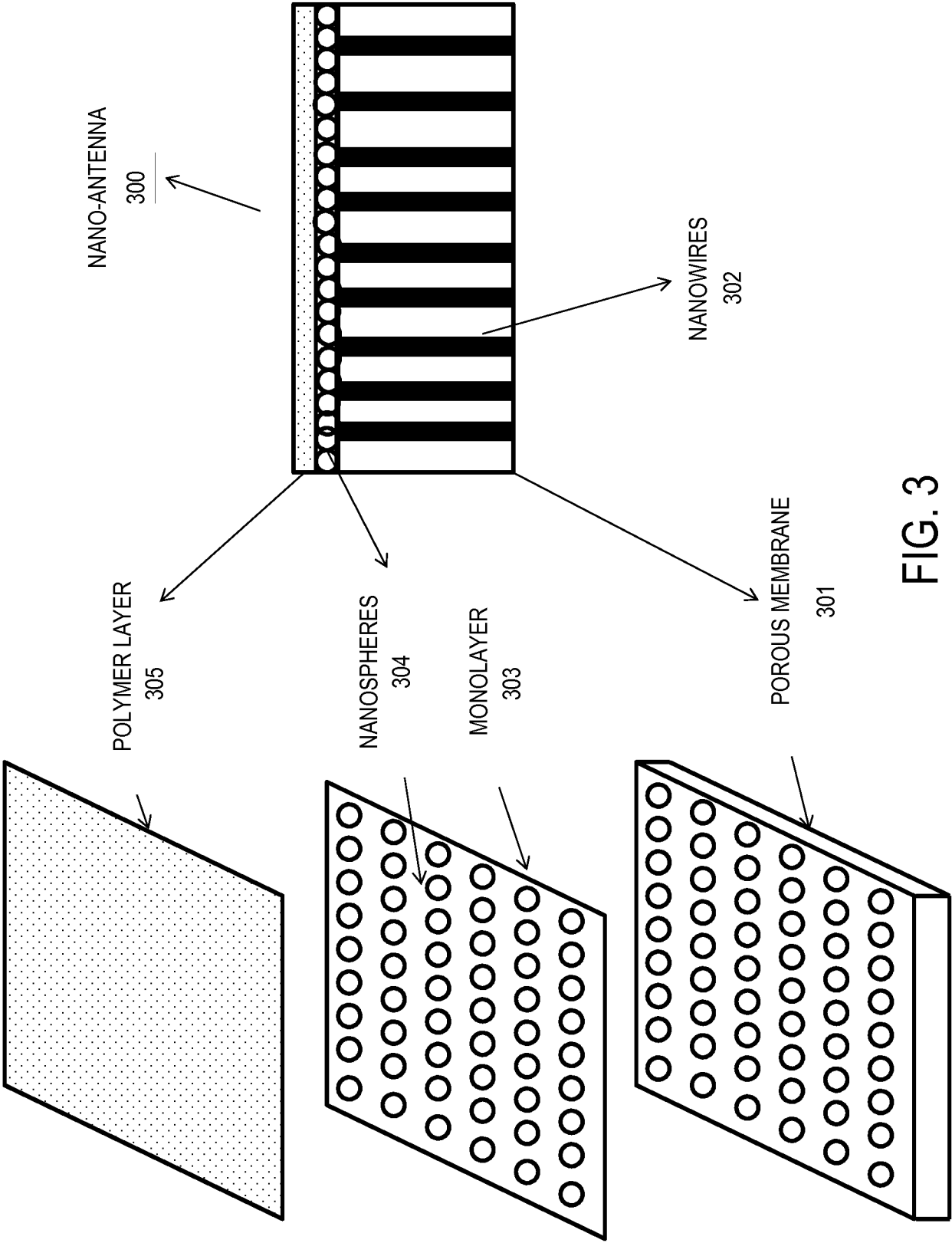


FIG. 3

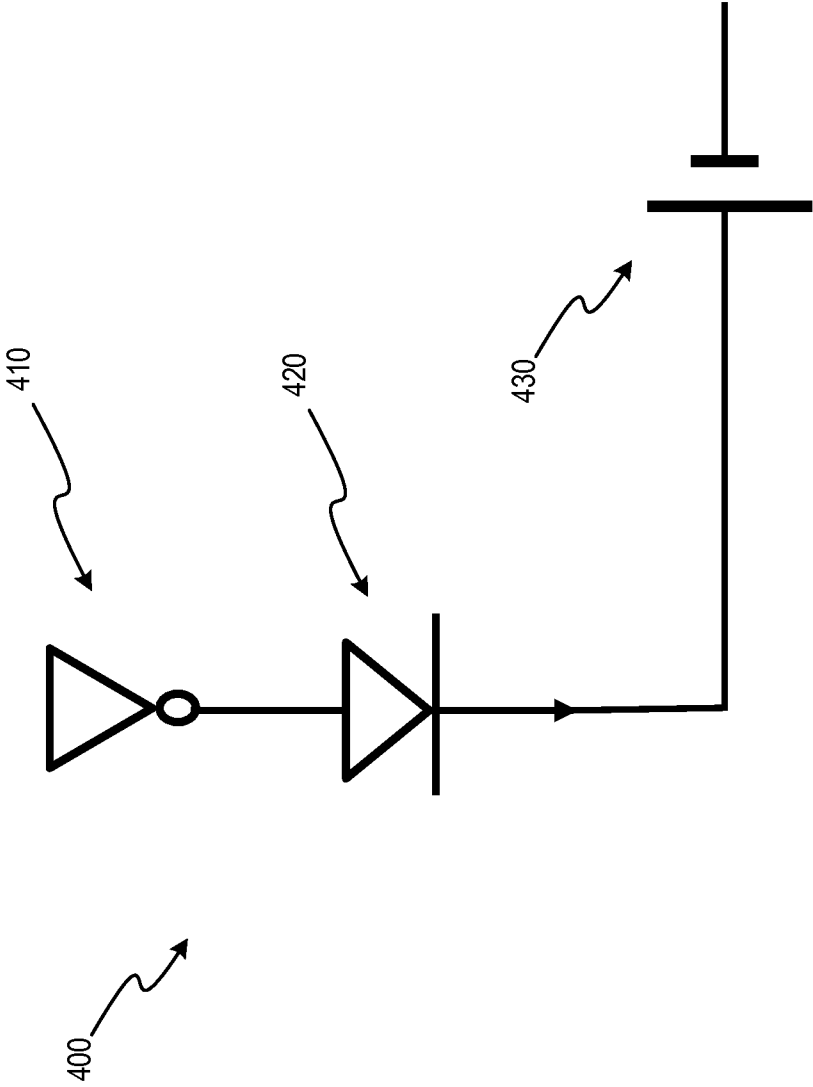


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 14/43671

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H01M 4/02 (2014.01)

CPC - Y02E 60/50; H01M 8/1004; H01M 4/8605

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8)- H01M 4/02 (2014.01)

CPC- Y02E 60/50; H01M 8/1004; H01M 4/8605

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 429/523; 429/209

Patents and NPL (classification, keyword; search terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used).

Databases: Google Scholar, Google Patent, PatBase

Search terms used: device, rectifying high-frequency signal device, first electrode, second electrode, zwitterionic molecules

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- Y	US 2006/0208252 A1 (Wessels et al.) 21 September 2006 (21.09.2006) para [0001], [0024], [0031], [0034].	1-6 ----- 7-22 and 31-36
X ----- Y	US 2010/0284086 A1 (Novack et al.) 11 November 2010 (11.11.2010) Abstract; para [0007], [0012], [0032]-[0033], [0035], [0048], [0050]-[0051], [0072]-[0074]; Fig. 8.	23-26, 30 and 37 ----- 22, 27-29 and 31-36
Y	Miskovsky et al. "Nanoscale Devices for Rectification of High Frequency Radiation from the Infrared through the Visible: A New Approach", Journal of Nanotechnology [online], 2012 [retrieved on 2014-11-19], Retrieved from the Internet: < http://www.hindawi.com/journals/jnt/2012/512379/ >, Vol 2012, pp 1-19. pg 3, col 2, para 2; pg 4, col 2, para 2-5; pg 14, col 1, Fig. 17; pg 14, col 1, para 3; pg 14, col 2, para 1-3; pg 15, col 2, para 1; pg 16, col 1, Figure 20.	7-22 and 27-29
Y	US 2007/0120114 A1 (Wang et al.) 31 May 2007 (31.05.2007) para [0035]-[0036], [0040]; Fig. 6; Fig. 14.	13 and 28

☐ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

19 November 2014 (19.11.2014)

Date of mailing of the international search report

01 DEC 2014

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-3201

Authorized officer:

Lee W. Young

PCT Helpdesk: 571-272-4300
PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 14/43671

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Group I: Claims 1-37, directed to device or system for harnessing energy

Group II: claims 38-45, directed to a method of rectifying a high-frequency signal comprising: transmitting the high-frequency signal through at least one layer of zwitterionic molecules

Group III: claims 46-59, directed to a method for harnessing light energy comprising: converting light energy into a high-frequency electric signal using at least one array of antennas that are configured to have a resonance frequency in a range of about 300 gigahertz (GHz) to about 10 petahertz (PHz)

Group IV: claims 60-83, directed to a method of making a device for rectifying a high-frequency signal comprising disposing at least one layer of zwitterionic molecules on the first electrode such that the at least one layer of zwitterionic molecules is in electrical contact with the second side of the first electrode.

---please see continuation in supplemental box ---

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-37

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

Box III: Lack of unity:

The inventions listed as Group I-IV do not relate to a single special technical feature under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Special Technical Feature:

Group II special feature is a method of rectifying a high-frequency signal comprising: transmitting the high-frequency signal through at least one layer of zwitterionic molecules, not required by other groups

Group III special feature is a method for harnessing light energy comprising: converting light energy into a high-frequency electric signal using at least one array of antennas that are configured to have a resonance frequency in a range of about 300 gigahertz (GHz) to about 10 petahertz (PHz), not required by other groups

Group IV special feature is a method of making a device for harnessing energy, the method comprising: disposing an array of antennas in a porous membrane, not required by other groups

Common Technical Features:

Group I and IV share the common technical feature of rectifying the high-frequency electric signal to form a rectified.

Groups I, III and IV share the common technical feature of an array of antennas.

However, these shared technical features do not represent a contribution over prior art, because the shared technical feature is being anticipated by US 5,030,962 A to Rees. Rees teaches rectifying the high-frequency electric signal to form a rectified (col 7, ln 27-20... mixer employed without an LO rectifies a high frequency signal to provide an output proportional to the square of the signal...) and an array of antennas (abstract).

Groups I and IV share the common technical feature of high-frequency signal, the device comprising: a first electrode; a second electrode; and at least one layer of zwitterionic molecules arranged in electrical contact with the first electrode and the second electrode such that the at least one layer of zwitterionic molecules provides a selectively activated electrical conduction path between the first electrode and the second electrode.

However, these shared technical features do not represent a contribution over prior art, because the shared technical feature is being anticipated by US 2005/0211292 A1 to Chittibabu et al. (hereafter 'Chittibabu'). Chittibabu teaches high-frequency signal, the device comprising (para [0006], photovoltaic cell) a first electrode; a second electrode; and at least one layer of zwitterionic molecules arranged in electrical contact with the first electrode and the second electrode (claim 50, photovoltaic cell, comprising a first electrode; a second electrode; and a charge carrier layer between the first and second electrodes, the charge carrier layer comprising: an electrolyte; and a zwitterionic compound...) such that the at least one layer of zwitterionic molecules provides a selectively activated electrical conduction path between the first electrode and the second electrode (claim 50; para [0032], ...one or more zwitterionic compounds in a charge carrier layer can allow for enhanced ability to control selective ion conduction within the charge carrier layer, which can improve the performance of the photovoltaic cell?).

As the shared technical features were known in the art at the time of the invention, they cannot be considered common technical features that would otherwise unify the groups. Therefore, Groups I-IV lack unity under PCT Rule 13.