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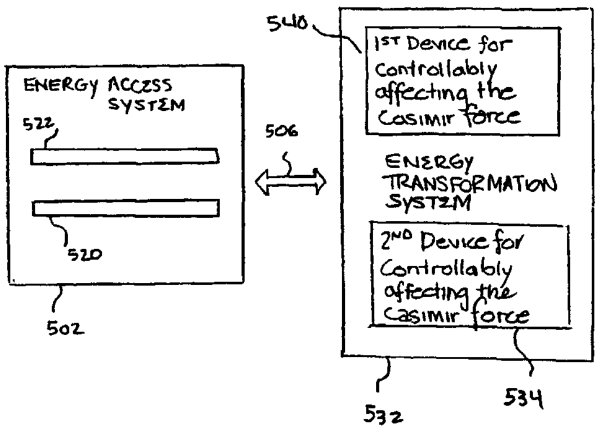
(54) Title: METHOD AND APPARATUS FOR ENERGY EXTRACTION



(57) Abstract: In some embodiments, the illustrative method defines an engine cycle comprising several state changes that allow for a net gain of energy from an underlying source force field. The potential for a net energy gain via the method results from the discovery that a Casimir force system can be rendered non-conservative. This is done by appropriately altering one or more of a variety of physical factors that affect the Casimir force, or by altering any of a variety of environmental factors that affect such physical factors. In various embodiments, the extracted energy is stored, used to power energy-consuming devices or used to actuate a micromechanical device. In one embodiment, the method is implemented using an energy extraction apparatus that comprises two spaced Casimir force-generating boundaries (520, 522) that are operatively coupled to an energy transformation system (532). The energy transformation system includes a first device that is operable to alter at least one physical factor of the system (540). The energy transformation system also includes a second device (534) that is operable to change the distance between the two Casimir force-generating boundaries, and further operable to maintain the distance between the boundaries while the first device alters the physical factor.

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METHOD AND APPARATUS FOR ENERGY EXTRACTION

Statement of Related Applications

This application claims priority of U.S. Provisional Application 60/135,868 filed May 25, 1999.

Field of the Invention

The present invention relates generally to the extraction of energy from a source force field, such as the quantum electromagnetic field.

Background of the Invention

Three hundred years ago, it was believed if all matter were removed from a region of space, a completely empty volume — a vacuum — results. One hundred years ago, it was known that even if all matter were removed from a region of space, that region is not truly empty because it still would contain thermal radiation. At that time, however, it was incorrectly believed that a vacuum could still be created by removing the thermal radiation, such as by cooling the region of space to absolute zero.

More recently, theory has predicted and experimentation has shown that a non-thermal radiation is present everywhere in the universe — even in regions that are otherwise devoid of matter and thermal radiation. This non-thermal radiation is believed to result from random fluctuations occurring at the quantum level that result in a continual creation and destruction of virtual particles. This radiation is often referred to as a "zero point field," or by the acronym "ZPF," and the energy that is associated with the field is referred to as "zero point energy," "vacuum energy," or simply by the acronym "ZPE."

In 1948, Hendrik B. J. Casimir theorized that two perfectly conducting, neutral planes that are situated in parallel relation to one another give rise to a mutually attractive force. This force, since referred to as "the Casimir force," results from the effect that the two planes have on the vacuum energy of a source field, such as an electromagnetic field, between the planes.

The Casimir force is believed to arise *solely* from the aforedescribed quantum-level activity. The presence of Casimir's two planes, or, in practical applications, two plates, restricts the allowed modes of oscillation of the random fluctuations in the quantum electromagnetic field.

In other words, the presence of the plates alters the boundary conditions of the electromagnetic field from free-field conditions. Consequently, the vacuum electromagnetic energy density in the space between the plates is less than the energy density outside of this space (*i.e.*, the number of virtual particles per unit volume in the space between the plates is less than the number of virtual particles per unit volume outside of this space). This difference or gradient in energy density gives rise to a force (*i.e.*, the Casimir force) that pushes the plates together.

While the Casimir force is "real" in the sense that is observable, the quantum electrodynamic ("QED") theory described above is not the only theory that adequately accounts for its existence. In particular, stochastic electrodynamics ("SED"), which provides a different interpretation, yields the same predictions.

The magnitude of the Casimir force, F_C, per unit area is given by the expression:

[1] $$F_C(s) = (\pi^2 / 240) \cdot (h^* c / s^4)$$

where: $\cdot$ means "multiply;"
$h^* = h/(2\pi)$
h is Planck's constant;
c is the speed of light in a vacuum;
s is the separation between the two conducting surfaces.

It is clear from expression [1] that as s approaches 0, the Casimir force $F_C(s)$ becomes large. In fact, the Casimir force per unit area between two plates separated by a distance s of about 0.1 microns is equivalent to the electrostatic force per unit area between the same two plates in the presence of a potential difference of about 100 millivolts.

ZPE is expected to exhibit infinite energy density and to be universally present, and may therefore be a limitless source of energy. This, not surprisingly, has tantalized researchers and spawned several efforts dedicated to ZPE research and commercialization. Such efforts notwithstanding, investigators have not as yet developed devices and methods suitable for commercially exploiting ZPE.

Summary of the Invention

Some embodiments of a method in accordance with the present invention define an engine cycle comprising several state changes that enable a net gain or recovery of energy that is accessed via Casimir force-generating boundaries (*e.g.*, plates, *etc.*).

One illustrative embodiment of a method for energy conversion/recovery in accordance with the present teachings comprises:

altering a physical factor that affects the Casimir force between two spaced Casimir force-generating boundaries;

changing the distance by which the two spaced Casimir force-generating boundaries are separated;

re-altering the physical factor to return it to its former value; and

returning the separation distance between the boundaries to its original value.

In one embodiment of the illustrative method, the altered physical factor is the concentration of free charge carriers in the Casimir force-generating boundaries. One way to alter the concentration of free charge carriers is to illuminate at least one of the Casimir force-generating boundaries (*e.g.*, plates) with photons. Another is to raise the temperature of such boundaries and yet another is to inject charge into at least one of the Casimir force-generating boundaries.

In some embodiments, the illustrative method includes a step of storing the energy accessed via Casimir force-generating boundaries after it is suitably transformed. In other embodiments, the method includes a step of delivering energy accessed via Casimir force-generating boundaries to other electrical consumers after it is suitably transformed. In still further embodiments, the method includes a step of actuating a micromechanical device with the energy accessed via the present method.

An illustrative apparatus for carrying out the inventive method comprises, in one embodiment, a system for accessing zero-point energy (*e.g.*, two Casimir force-generating boundaries) that is operatively coupled to an energy transformation system. In some embodiments, the energy transformation system includes a first device that is operable to alter at least one physical factor of the system, and a second device that is operable to change a distance between the Casimir force-generating boundaries. The first and second devices advantageously operate independently of each other such that, at the same time, the physical factor can be affected and spacing between the boundaries can be controlled.

The structure of the energy transformation system varies as a function of the nature of the energy transformation (*e.g.*, to electrical energy for storage, to electrical energy for direct use, to mechanical/kinetic energy for actuation, *etc.*).

Underlying the illustrative engine cycle, methods and apparatuses described herein is a discovery that a Casimir force system can be rendered *non-conservative* by appropriately altering one or more physical factors that affect the Casimir force, or by altering one or more environmental factors that affect such physical factors.

More particularly, it has been discovered that by altering a physical factor that affects the Casimir force, an apparatus can be created in which more energy is expended by the Casimir force in drawing the Casimir force-generating boundaries together than it takes to pull them apart. As a consequence, when such boundaries are pulled apart, a net energy transfer results. The cycle can be repeated as long as the apparatus lasts.

Unlike the gravitational force, the value of which does not depend on the properties of a mass being acted upon, the Casimir force depends upon a variety of physical factors that can be changed if a specific energy price is paid. When such a penalty is smaller, in absolute terms, than the total work done by the Casimir force in a cycle, a net amount of energy accessed via Casimir force-generating boundaries is available for recovery. When the penalty is larger, in absolute terms, than the total work done by the Casimir force in a cycle, then the present methods and apparatuses function simply to transform energy (*i.e.*, as a transducer), but yield no net gain of energy.

Some embodiments of the present invention appear to contradict typical interpretations of the principle of conservation of energy but, in fact, do not. Energy accessed via Casimir force-generating boundaries is made available *because* of well-known energy conservation arguments, not in spite of them.

Brief Description of the Drawings

FIG. 1 depicts a well-known Casimir force-generating system.

FIG. 2 depicts an illustrative engine cycle in accordance with the present teachings.

FIG. 3 depicts a method for energy extraction in accordance with the illustrated embodiment of the present invention.

FIG. 4 depicts the dependence of the Casimir force on plate separation as a function of dopant level.

FIG. 5 depicts, figuratively, an illustrative embodiment of energy extraction apparatus in accordance with the present teachings.

FIG. 6 depicts an embodiment of the illustrative energy extraction apparatus depicted in FIG. 5. The apparatus is depicted at the end of a first state change in accordance with the illustrative cycle of FIG. 2 and at the end of a first step in accordance with the illustrative method of FIG. 3.

FIG. 7 depicts the energy extraction apparatus shown in FIG. 6, but depicts the apparatus at the end of a second state change in accordance with the illustrative cycle of FIG. 2 and at the end of a second step in accordance with the illustrative method of FIG. 3.

FIG. 8 depicts the energy extraction apparatus shown in FIG. 6, but depicts the apparatus at the end of a third state change in accordance with the illustrative cycle of FIG. 2 and at the end of a third step in accordance with the illustrative method of FIG. 3.

FIG. 9 depicts the energy extraction apparatus shown in FIG. 6, but depicts the apparatus at the end of a fourth state change in accordance with the illustrative cycle of FIG. 2 and at the end of a fourth step in accordance with the illustrative method of FIG. 3.

FIGS. 10a – 10e depict the cycling of two control variables in an illustrative method in accordance with the present teachings.

FIG. 11 depicts a further illustrative embodiment of a method for energy extraction in accordance with the present teachings.

FIG. 12 depicts an arrangement whereby energy that is recovered is used to drive a device that requires electricity to operate.

FIG. 13 depicts an arrangement whereby recovered energy is used as an actuating force.

FIG. 14 depicts an illustrative embodiment of a particle accelerator in accordance with the present teachings.

FIG. 15 depicts an illustrative embodiment of a particle decelerator in accordance with the present teachings.

FIG. 16 depicts a first illustrative method for accelerating/decelerating particles in accordance with the present teachings.

FIG. 17 depicts a second illustrative method for accelerating/decelerating particles in accordance with the present teachings.

FIG. 18 depicts a third illustrative method for accelerating/decelerating particles in accordance with the present teachings.

Detailed Description of the Invention

As stated in the *Background* section, the Casimir force arises (in at least one interpretation) from the imposition of boundary conditions on a source force field, such as the quantum electromagnetic field, the "strong" force field, the gravitational force field, and the "weak" force field. Although the illustrative methods and apparatuses described herein are directed to systems in which the Casimir force arises from interactions with the quantum electromagnetic field, the present invention is also applicable to systems in which the Casimir force arises from interactions with the "strong" force field, the gravitational force field, and the "weak" force field.

It will be understood that the illustrative embodiments of the present invention do not, literally, "change" or "transform" zero point energy to another form of energy. In particular, in accordance with some embodiments of an illustrative apparatus in accordance with the present invention, Casimir force-generating boundaries interact or cooperate with an energy transformation system. Such interactions include, for example, moving a linkage that engages another device or affecting an electrostatic field. To the extent such interactions occur, zero-point energy is thus transformed or changed to another form of energy — be it electrical, kinetic, *etc.*

As used in this *Specification*, the phrase "**Casimir force-generating boundaries**" means any object (mass) or force field that is capable of restricting the allowed modes of oscillation of random quantum-level fluctuations of a source force field or is otherwise capable of altering the boundary conditions of a source force field from free-field conditions. Such objects include, without limitation, plates, spheres, particles (even atomic and subatomic particles) and the like. Regarding force fields, any secondary force field (*i.e.*, secondary with respect to a source force field) including, without limitation, an electromagnetic field, will interact with the source force field therefore altering the boundary conditions of the source force field from free-field conditions.

As used in this *Specification*, the phrase "**energy accessed via Casimir force-generating boundaries**" means energy (*e.g.*, zero point energy) arising from a source force field (*e.g.*, quantum electromagnetic field, *etc.*) that is manipulated via the Casimir force.

As used in this *Specification*, the phrases "**net gain**," "**net exchange**," and the term "**recovery**," when used in conjunction with the term "energy," mean that more energy is withdrawn from a system than is added thereto. The phrases "**convert**" or "**conversion**," when used in conjunction with the term "energy," mean that while energy accessed via Casimir force-generating boundaries is harnessed for use, no net gain of energy is realized via the present methods or apparatuses. As used in the *Specification*, the term "**extraction**," when used in conjunction with the term "energy," is meant to refer generally to both energy conversion and energy recovery, or to refer to either energy conversion and energy recovery.

The illustrative embodiments described herein are improvements on a simple well-known Casimir force-generating system, which is depicted in FIG. 1. In particular, FIG. 1 depicts two Casimir force-generating boundaries $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$. Casimir force-generating boundaries $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$ are separated by distance $\boldsymbol{s}$. Casimir force-generating boundary $\boldsymbol{P_1}$ is movable towards (and away from) Casimir force-generating boundary $\boldsymbol{P_2}$.

As will be appreciated by those skilled in the art, when performing Casimir force calculations, Casimir force-generating boundaries $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$ are considered to be slabs (typically dielectric) having "semi-infinite" thickness. Thus, for such calculations, Casimir force-generating boundary $\boldsymbol{P_1}$ (shown as a thin plate-like structure in FIG. 1) is assumed to extend infinitely to the left (in FIG. 1), beginning at the surface of $\boldsymbol{P_1}$ that is proximal to boundary $\boldsymbol{P_2}$. Similarly, Casimir force-generating boundary $\boldsymbol{P_2}$ extends infinitely to the right, beginning at the surface of $\boldsymbol{P_2}$ that is proximal to boundary $\boldsymbol{P_1}$.

Semi-infinite boundary $\boldsymbol{P_1}$ has dielectric properties $\varepsilon_1(\omega)$, and semi-infinite boundary $\boldsymbol{P_2}$ has dielectric properties $\varepsilon_2(\omega)$. The region between such boundaries is assumed to have dielectric properties $\varepsilon_3(\omega)$. When performing quantitative estimates, it is typically assumed that $\varepsilon_1(\omega) = \varepsilon_2(\omega)$, and $\varepsilon_3(\omega) = 1$. Real plates, of course, have a non-infinite thickness. In many cases, the non-infinite thickness of real plates does not alter the quantitative results predicated on the assumption of semi-infinite boundaries.

It will be recognized that the Casimir force is a function of the specific geometry of the Casimir force-generating system. For example, in a system comprising two parallel boundaries as in FIG. 1, the Casimir force is attractive, but in a system comprising two halves of thin metal spherical shells the Casimir force is repulsive. In addition, changing the physical orientation of spaced boundaries $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$ from "parallel" to "not parallel" will affect the Casimir force. And, of course, varying the angle defined between two non-parallel boundaries will vary the Casimir force. Also, bending a boundary (*see, e.g.*, FIG. 6) will affect the Casimir force. The ability to extract energy, and the extent of such extraction in accordance with the present teachings, can, therefore, vary as a function of the specific arrangement used. It will be understood by those skilled in the art that embodiments of the present invention can use Casimir force-generating boundaries that are arranged in many specific arrangements other than in spaced, parallel relation as depicted in FIG. 1.

Referring again to FIG. 1, the Casimir force $\boldsymbol{F_C}$ between $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$ is depicted as an attractive force that is a function of:

1. the distance $\boldsymbol{s}$ between the surfaces;
2. every physical factor Y_i that determines the dielectric and other properties (*e.g.*, surface roughness, *etc.*) of the materials that comprise the system (*e.g.*, such as the material that comprises boundaries $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$)
3. every environmental factor X_j that affects each physical factor Y_i.

Regarding item 2, the concentration of free carriers in $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$ can, for example, affect the magnitude of the Casimir force $\boldsymbol{F_C}$ (other parameters affecting the Casimir force are described later in this *Specification*).

With regard to item 3, environmental factors X_j that affect physical factors Y_i, include, without limitation, the absolute temperature and the radiation density. And, the dependence of physical factors Y_i is in addition to any intrinsic dependence of Casimir force $\boldsymbol{F_C}$ on temperature. Thus, for any given arrangement of $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$, the Casimir force $\boldsymbol{F_C}$ is a function of the kind:

$$F_C = F_C(s;\ Y_1(X_1, X_2, \ldots);\ Y_2(X_1, X_2, \ldots);\ \ldots) \qquad [2]$$

FIG. 2 depicts a plot of illustrative "engine" cycle **200** for use in the extraction of energy accessed via Casimir force-generating boundaries in accordance with the present teachings. A method **300** based on engine cycle **200** is depicted in FIG. 3.

In FIG. 2, the abscissa (*i.e.*, the x-axis) represents distance $\boldsymbol{s}$ between two Casimir force-generating boundaries $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$ (*see*, FIG. 1), and the ordinate (*i.e.*, the y-axis) represents the absolute value of the Casimir force $\boldsymbol{F_C}$.

Illustrative engine cycle **200** is described, for pedagogical purposes, with reference to points ***A***, ***B***, ***C*** and ***D***. It will be understood that such points are arbitrary and are used for purposes of illustration, not limitation. Moreover, it will be recognized that illustrative engine cycle **200** proceeds in either of two directions; that is, cycle **200** is reversible.

Illustrative engine cycle **200** comprises state changes **202, 204, 206** and **208** that affect the value of the Casimir force $\boldsymbol{F_C}$. The description of cycle **200** begins at point $\boldsymbol{A}$, wherein the Casimir force $\boldsymbol{F_C}$ has a value $F_C{}^A$ that is a function of distance $\boldsymbol{s}$, and all physical factors $Y_i(X_j)$:

$$[3] \qquad F_C{}^A = F_C(s_A; Y_{1A}(X_{1A}, X_{2A}, \ldots); Y_{2A}(X_{1A}, X_{2A}, \ldots); \ldots)$$

Beginning at point $\boldsymbol{A}$, a state change or transformation **204** is effected that ends at point $\boldsymbol{B}$. To implement state change **204** (*i.e.*, $\boldsymbol{A} \rightarrow \boldsymbol{B}$), the distance $\boldsymbol{s}$ between the Casimir force-generating boundaries is changed, but all other physical and environmental factors $Y_i(X_j)$ that affect the Casimir force are assumed to be substantially constant and equal to their value at point $\boldsymbol{A}$. The change in distance $\boldsymbol{s}$ results, of course, in a change in the value of the Casimir force $\boldsymbol{F_C}$ to:

$$[4] \qquad F_C{}^B = F_C(s_B; Y_{1A}(X_{1A}, X_{2A}, \ldots); Y_{2A}(X_{1A}, X_{2A}, \ldots); \ldots)$$

In state change **204** of illustrative cycle **200**, the Casimir force $\boldsymbol{F_C}$ increases since distance $\boldsymbol{s}$ is decreased, in accordance with expression [1].

At point $\boldsymbol{B}$, another state change **206** occurs that ends at point $\boldsymbol{C}$. As depicted in FIG. 2, during state change **206** (*i.e.*, $\boldsymbol{B} \rightarrow \boldsymbol{C}$), the Casimir force-generating boundaries (*e.g.*, $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$) are held substantially constant such that there is no change in distance $\boldsymbol{s}$. Rather, a change is effected to physical factors $Y_i(X_j)$. Since, by definition, such physical factors affect the Casimir force, the change in physical factors $Y_i(X_j)$ changes the value of Casimir force $\boldsymbol{F_C}$ to:

$$[5] \qquad F_C{}^C = F_C(s_B; Y_{1C}(X_{1C}, X_{2C}, \ldots); Y_{2C}(X_{1C}, X_{2C}, \ldots); \ldots)$$

In expression [5], distance $\boldsymbol{s}$ is referenced as "s_B" to emphasize that there is no change in this variable (*i.e.*, $s_C = s_B$) during state change **206**.

From point $\boldsymbol{C}$, state change **208** occurs that ends at point $\boldsymbol{D}$. In state change **208** (*i.e.*, $\boldsymbol{C} \rightarrow \boldsymbol{D}$), distance $\boldsymbol{s}$ is advantageously returned to its initial value (*i.e.*, $s_D = s_A$), while all other parameters are held substantially constant. The value of Casimir force $\boldsymbol{F_C}$ at point $\boldsymbol{D}$ due to state change **208** is:

$$[6] \qquad F_C{}^D = F_C(s_A; Y_{1C}(X_{1C}, X_{2C}, \ldots); Y_{2C}(X_{1C}, X_{2C}, \ldots); \ldots)$$

Finally, in state change **202** that ends at point $\boldsymbol{A}$ (*i.e.*, $\boldsymbol{D} \rightarrow \boldsymbol{A}$), physical factors $Y_i(X_j)$ are advantageously restored to their initial values so that the value of Casimir force $\boldsymbol{F_C}$ is given by:

[7] $$F_C^{\,A} = F_C(s_A; Y_{1A}(X_{1A}, X_{2A}, \ldots); Y_{2A}(X_{1A}, X_{2A}, \ldots); \ldots)$$

The total energy, W_{tot}, available from engine cycle **200** is given by:

[8] $$W_{tot} \equiv (W_{DA} - W_{BC}) - W_{Cas}$$

where: W_{BC} represents an amount of energy transferred from the system ($W_{BC} > 0$) to create state change **206**;
W_{DA} represents an amount of energy transferred to the system ($W_{DA} < 0$) to create state change **202**; and
W_{Cas} is the total mechanical work done by Casimir force F_C over its closed path (*i.e.*, the area enclosed by the curves that define cycle **200**).

The quantity W_{DA}, or state change **202**, represents the addition of energy to engine cycle **200**. The quantity W_{BC}, or state change **206**, represents the removal of energy from engine cycle **200**. The removal or addition of such energy can be effected in numerous ways, a few of which are described later in this *Specification*.

The work done by the Casimir force, W_{Cas}, is given by:

[9] $$W_{Cas} \equiv \oint F_C(s; Y_i(X_j))\, ds$$

Conventional energy conversion systems are conservative. As such, the total energy, W_{tot}, available from such systems is zero. In other words, the energy "out" of such systems is never greater than the energy that is added to such systems. In view of inefficiencies (*e.g.*, friction, *etc.*) in practical systems, the *useful* energy out of a system is typically far less than the energy added to the system.

Consider, for example, a hydroelectric plant. Water cannot be transported back up to the top of a water falls without expending an amount of energy that is exactly equal to the kinetic energy obtained from that same water as it falls through turbines at the bottom of the water falls. This is well understood from the conservative properties of the gravitational force. Indeed, a substantial amount of experimentation has consistently shown that the gravitational constant does not depend on the chemical properties of the materials involved or on their temperature.

In contrast to the gravitational constant, *every present theory of the Casimir force between two surfaces predicts a dependence on those very physical or environmental factors* (*see* Expression [2], above). The tendency to liken the exchange of energy accessed via Casimir force-generating boundaries to that of hydroelectric energy production and other conventional forms of energy production is therefore inappropriate and incorrect.

The present inventor has discovered that by appropriately altering any of the physical factors $Y_i(X_j)$, a Casimir force system can be made *non-conservative* such that a net exchange of energy accessed via Casimir force-generating boundaries is possible, at least theoretically, such as via engine cycle **200**. Unfortunately, the withdrawal and input of energy in conjunction with cycle **200** is not readily correlated to the various state changes the make up the cycle. The energy balance is determined by netting the various contributions as indicated in expression [8].

Considering the cycle in its entirety, however, the possibility for energy recovery is manifest. Engine cycle **200** creates a situation in which more work is required to draw the plates together (work done by the Casimir force) than to pull them apart (energy added to the system). And, when $(W_{DA} - W_{BC}) - W_{Cas} < 0$, there is a net recovery of energy — energy accessed via Casimir force-generating boundaries.

The difference in work described above is observable in FIG. 2. In particular, the change in the Casimir force is greater for the state change from point ***A*** to point ***B*** (work done by the Casimir force), wherein the distance between the plates is decreased, than for the state change from point ***C*** to point ***D***, wherein the distance between the plates is increased (energy is supplied to pull the plates apart). Again, what makes this possible is a change in the value of physical factors $Y_i(X_j)$.

Specifically, at points ***A*** and ***B***, the physical factors are defined by a first set of values (*see* expressions [3] and [4]), while at points ***C*** and ***D***, the physical factors are defined by a second set of values (*see* expressions [5] and [6]). Since the Casimir force is a function of physical factors $Y_i(X_j)$, the change in value of the physical factors results in a difference in the Casimir force for a given distance between the Casimir force-generating boundaries (*e.g.*, compare point ***D*** to point ***A***). And, more importantly in the context of the present invention, the rate of change of the Casimir force is different.

Recovery of energy from a source energy field in accordance with illustrative engine cycle **200** is readily distinguishable from, for example, net gain of energy from an endless recycle of water from the bottom to the top of a water falls in Escher-like fashion. Again, unlike the gravitational force, the Casimir force depends upon a variety of physical factors that can be changed if a specific energy price is paid. When such a penalty is smaller, in absolute terms, than the total work done by the Casimir force in cycle **200**, a net amount of energy accessed via Casimir force-generating boundaries is available for recovery.

This discovery appears to contradict typical interpretations of the principle of conservation of energy. In fact, it does not; energy accessed via Casimir force-generating boundaries is made available *because* of well-known energy conservation arguments, and not in spite of them. In fact, one or more well-established physical principles would have to be abandoned to reach the conclusion that, in the illustrative engine cycle **200** described herein, the Casimir force is conservative. In this context, it should be noted that the interpretative details will differ as between a QED-based description of the Casimir force and a SED-based description of the Casimir force.

Notwithstanding the foregoing, if a net gain of energy accessed via Casimir force-generating boundaries is not realized in practice due to technological or other unanticipated limitations, then engine cycle **200** provides energy conversion — that is, the cycle simply provides a transformation or a transducer function. For further theoretical treatment of the illustrative engine cycle described herein, including evaluation of the net energy gain, *see*, Pinto, F., "On the Engine Cycle of an Optically Controlled Vacuum Energy Transducer," Phys. Rev. B, vol. 60, issue 2, Dec. 1, 1999, p. 14740+, incorporated herein by reference.

FIG. 3 depicts a flow diagram of an illustrative method **300** for extraction of energy accessed via Casimir force-generating boundaries, in accordance with an illustrated embodiment of the present invention. Method **300** is based on illustrative engine cycle **200**. The steps or operations of illustrative method **300** are ordered in a convenient manner for description. In particular, such steps are ordered to facilitate reference to the foregoing description of engine cycle **200**. It will be appreciated from the description of engine cycle **200** that the order in which the various operations or steps of illustrative method **300** are carried out is arbitrary.

Like engine cycle **200** upon which it is based, method **300** will be described, as appropriate, in the context of a system having two Casimir force-generating boundaries, such as two plates, one fixed and the other movable, that are spaced from and in parallel relation to one another. For clarity of presentation, the basic operations of illustrative method **300** are described first. That description is followed by a description of the energy flow into and out of a system carrying out method **300**.

Referring to FIG. 3, in a first operation **302** of method **300**, at least one physical factor Y_i that affects the value of the Casimir force is altered. Starting, for convenience, at point $\boldsymbol{D}$ in engine cycle **200**, operation **302** corresponds to state change or transformation **202** (*i.e.*, $\boldsymbol{D} \rightarrow \boldsymbol{A}$ state change). As described in further detail later in this *Specification* in conjunction with FIGS. 6-8, in some embodiments, operation **302** requires the addition of energy to the system.

Examples of physical factors that are altered in various embodiments include, without limitation, the concentration of free charge carriers and the location and strength of any absorption bands in the material comprising the Casimir force-generating boundaries. In other embodiments, altered physical factors include the material properties of the Casimir force-generating boundaries. Such material properties include, without limitation, dielectric properties and surface roughness.

An additional alterable physical factor Y_i includes the specific geometry of the Casimir force generating system. For example, changing the physical orientation of spaced boundaries $\boldsymbol{P}_1$ and $\boldsymbol{P}_2$ from "parallel" to "not parallel" will affect the Casimir force. And, of course, varying the angle defined between two non-parallel boundaries will vary the Casimir force. Also, bending a boundary (*see*, *e.g.*, FIG. 6) will affect the Casimir force.

The material(s) comprising the Casimir force-generating boundaries are suitably selected as a function of the physical factor(s) Y_i chosen for alteration. For example, in an embodiment wherein the altered physical factor is the concentration of free charge carriers, the boundaries are advantageously semiconductors or compound semiconductors. Illustrative semiconductors (for embodiments wherein the altered physical factor is the concentration of free charge carriers) include, without limitation, silicon (Si), germanium (Ge), and compound semiconductors such as, without limitation, gallium arsenide (GaAs), indium gallium arsenide (InGaAs) and indium antimonide (InSb).

Moreover, in some embodiments, the boundaries comprise doped semiconductors and doped compound semiconductors, including, without limitation, phosphorus-doped silicon and indium antimonide that includes naturally occurring impurities. In some embodiments, dopants are selected based on their relative ease of ionization.

By way of illustration, FIG. 4 depicts plots showing the change in Casimir force due to a variation in free charge carriers, as effected via various dopant concentrations. Plots **410**, **412**, **414** and **416** show the Casimir force as a function of plate spacing for plates formed from crystalline silicon that is doped with donor phosphorus at concentrations of: $0.011 \times 10^{19}\ cm^{-3}$,

0.52×10^{19} cm^{-3}, 10×10^{19} cm^{-3} and 3.8×10^{21} cm^{-3}, respectively. High dopant concentrations generate more free charge carriers resulting in an increase in the Casimir force. More energy is, however, typically required to generate such larger numbers of free charge carriers such that there may be no benefit to using ultra-heavily doped materials.

In some embodiments, operation **302** is implemented by *directly* altering physical factor Y_i. Continuing with the previous example wherein the altered physical factor is the concentration of free charge carriers, that concentration is directly altered, in one embodiment, by illuminating Casimir force-generating boundaries $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$. In another embodiment, the concentration of free charge carriers is directly altered by injecting charge to boundaries $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$. Various other ways known to those skilled in the art to directly affect the free carrier concentration may suitably be used to implement operation **302**.

In other embodiments, operation **302** is implemented by *indirectly* altering physical factor Y_i, such as by altering environmental factor X_j that affects the physical factor Y_i. One such readily altered environmental factor that is suitable for indirectly altering physical factor Y_i is temperature. In the specific example of the concentration of free charge carriers as the altered physical factor Y_i, changing the temperature of Casimir force-generating boundaries $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$ causes thermal ionization of donor dopants and a consequent increase in carrier concentration.

The phrase "**altering a physical factor**," as used in this *Specification*, is meant to encompass both direct alteration of physical factor Y_i, as well as indirect alteration of physical factor Y_i, such as by altering environmental factor X_j that affects the physical factor Y_i, as described above. As used herein, the phrase "altering a physical factor" explicitly excludes changing the distance between Casimir force-generating boundaries $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$. Moreover, unless otherwise indicated, the phrase "**physical factor**" is meant to include physical factors, and environmental factors that affect the physical factors.

Continuing with the description of illustrative method **300**, distance $\boldsymbol{s}$ between the two Casimir force-generating boundaries $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$ is changed in operation **304**. With reference to cycle **200**, operation **304** corresponds to state change **204** (*i.e.*, $\boldsymbol{A \rightarrow B}$). The manner in which operation **304** is accomplished depends, of course, on the apparatus chosen for implementing method **300**. An embodiment of an apparatus suitable for implementing method **300** is described later in this *Specification* in conjunction with FIGS. 5-11.

In operation **306**, the physical factor(s) Y_i that were altered in operation **302** are again altered. In one embodiment, the altered physical factors(s) are advantageously returned to their original value(s) (*e.g.*, the value(s) at point ***D***). Such an embodiment corresponds to state change **306** (*i.e.*, ***B*** → ***C***) depicted in cycle **200** (FIG. 2).

In other embodiments, the altered physical factor(s) are altered in an appropriate "direction," but not returned to their original value(s). For example, with reference to FIG. 2, in other embodiments, the physical factor(s) are altered such that the Casimir force decreases as in the transformation ***B*** → ***C***, but the alteration does not fully reduce the Casimir force to the value at point ***C*** such that the physical factor is not returned to its original value. Rather, the state change results in a value of the Casimir force that is more or less than the value at point ***C***. And, in a further embodiment, different physical factor(s) are altered in operation **306** than were altered in operation **302**.

In operation **308**, distance ***s*** between the two boundaries P_1 and P_2 is again changed. In particular, the movable surface is advantageously returned to its original position. Thus, at the completion of operation **308**, distance ***s*** between the boundaries is advantageously the same as it was before they were moved in operation **304**. Operations **302-308** result in the extraction of energy accessed via Casimir force-generating boundaries. Operations **310A**, **310B** and **310C**, described later in this *Specification*, pertain to the disposition of such extracted energy.

Illustrative method **300** is described further later in this *Specification* with reference to FIGS. 6-11, which depict an embodiment of illustrative energy extraction apparatus **500** (*see* FIG. 5) carrying out illustrative method **300.**

Illustrative energy extraction apparatus **500** is operative, when carrying out illustrative method **300**, to extract energy from a source force field, such as the quantum electromagnetic field. Illustrative energy extraction apparatus **500** comprises energy access system **502** and energy transformation system **532** that interact or cooperate with one another, as indicated by bi-directional indicator **506.**

Energy access system **502** provides access to a source force field, such as the quantum electromagnetic field (QED interpretation). Energy transformation system **532** transforms the accessed energy to a convenient form for exploitation (*e.g.*, electrical energy, kinetic energy, *etc.*), among other functions. In some embodiments, energy access system **502** and energy transformation system **532** include, collectively, all elements that are necessary for carrying out method **300.**

Energy access system **502** advantageously comprises Casimir force-generating boundaries **522** and **520**. Energy from a source force field is accessed via Casimir force-generating boundaries **522** and **520**. Energy transformation system **532** advantageously includes a first device/system **540** and a second device/system **534** that, independently of one another, are operable to controllably affect the Casimir force accessed through energy access system **502**.

In the illustrative embodiments, first device **540** that is operable to alter a physical factor of energy access system **502** that affects the Casimir force. In embodiments in which energy access system **502** comprises Casimir force-generating boundaries **522** and **520**, device **540** advantageously alters a physical factor of at least one of boundaries **522** and **520**. In some embodiments, device **540** is a laser.

In the illustrative embodiments, second device **534** is operable to controllably change the distance between two Casimir force-generating boundaries. In some embodiments, device **534** is a controlled power supply.

The particular physical configuration of energy transformation system **532** varies with the nature of the energy transformation (*e.g.*, transformation to electrical energy, transformation to kinetic energy, *etc.*). FIGS. 6-9 illustrate one specific embodiment of energy extraction apparatus **500**, wherein energy transformation system **532** is physically configured to transform energy accessed via Casimir force-generating boundaries to electrical energy.

In the embodiment depicted in FIG. 6, energy extraction apparatus **500** comprises four plates **518**, **520**, **522**, **524**, interrelated as shown. In the embodiment depicted in FIG. 6, energy access system **502** comprises plates **522** and **520**. In particular, plates **522** and **520** function as the Casimir force-generating boundaries.

Plates **520** and **518** are physically separated and electrically insulated via standoffs **526**, plates **522** and **520** are physically separated and electrically insulated via standoffs **528**, and plates **524** and **522** are physically separated and electrically insulated via standoffs **530**. Plate **522** is movable upwardly and downwardly, while plates **518**, **520** and plate **524** are non-moving. Standoffs **526**, **528** and **530** comprise an electrically insulating material, such as, without limitation, silicon oxide and silicon nitride.

Energy extraction device **500** further includes energy transformation system **532**. In the illustrated embodiment, energy transformation system **532** is physically configured to carry out operation **310A** of method **300**, wherein energy accessed via Casimir force-generating boundaries is transformed to electrical energy and stored.

Energy transformation system **532** includes plates **518** and **524**, controlled bi-directional power supply **534** that is electrically connected to each plate **518, 520, 522** and **524**, resistor **536** that represents the internal resistance of bi-directional power supply **534**, switch **538** and radiation source **540**, electrically connected as shown. In some embodiments, radiation source **540** is a source of monochromatic radiation such as a laser.

In embodiments in which the physical factor is altered via a radiation source, such as radiation source **540**, and (1) the altered physical factor is the concentration of free charge carriers and (2) the Casimir force-generating boundaries **522** and **520** are doped with an impurity to supplement free charge carrier generation, then the radiation source is advantageously tuned to the ionization level of the impurity. Radiation source **540** is powered by a controlled power supply (not shown).

When switch **538** is closed, controlled bi-directional power supply **534** is operable to supply charge to and receive charge from, as appropriate, a first capacitive structure defined by side **524a** of plate **524** and side **522b** of plate **522**. Further, controlled bi-directional power supply **534** is operable to supply charge to and receive charge from, as appropriate, a second capacitive structure defined by side **520b** of plate **520** and side **518a** of plate **518**.

The illustrative arrangement of four plates **518, 520, 522** and **524** depicted in FIG. 5 results in an equal distribution of charge on facing sides **524a** and **522b** of respective plates **524** and **522**, and on facing sides **520b** and **518a** of respective plates **520** and **518**. These sides, which must be conductive, receive substantially all the charge with substantially no charge being received by facing sides **522a** and **520a** of respective plates **522** and **520**. This is depicted in FIG. 5 by the presence of "+" and "-" on the appropriate sides of plates **518, 520, 522** and **524**. Plates **524** and **518** are advantageously maintained at the same potential, and plates **522** and **520** are advantageously maintained at the same potential. Given the illustrative arrangement, electrostatic forces between plates **522** and **520** are kept quite low and can, therefore, be neglected.

Plates **522** and **520** comprise a material that is selected, for example, based on the physical factor that is going to be altered in accordance with method **300**. Suitable materials for an embodiment wherein the concentration of free charge carriers is altered have already been described. It is within the capabilities of those skilled in the art, using available reference materials and published articles, to suitably select materials as a function of physical factor being altered. In most cases, simply experimentation is advantageously performed to confirm materials selection and to identify, as desired, a preferred material.

Since, in the illustrated embodiment, surfaces and **522b** and **520b** are conductive, and since, in some embodiments, plates **522** and **520** are not conductive, conductivity must be imparted to surfaces **522b** and **520b**. Conductivity may be imparted, for example, by coating those surfaces with a conductive material (*e.g.*, aluminum, *etc.*). Plates **524** and **518** comprise a conductive material, or, in some embodiments, conductivity is imparted by depositing a conductive layer on the plates or appropriately doping the plates.

The "stack" of spaced plates **518, 520, 522** and **524** comprising energy extraction device **500** of FIG. 6 is formed using techniques that are now quite familiar to those skilled in the art. In some embodiments, using such conventional techniques, hundreds, thousands or even millions of discrete apparatuses **500** are formed on a single substrate to provide a suitable amount of energy output as required for a given application.

In one embodiment, the stack of spaced plates is formed using surface micromachining technologies. Typical of such technology is SUMMiT V Technology offered by Sandia National Laboratories (www.mdl.sandia.gov/micromachine/summit5.html). SUMMiT V is a five-level polycrystalline silicon surface micromachining process (one ground plane and four mechanical or releasable layers). Like most MEMS (micro electro mechanical systems) fabrication technology, the SUMMiT V process involves alternately depositing a film, photolithographically patterning the film, and then chemical etching.

Successive mechanical layers (*i.e.*, the polysilicon layers) are separated by, for example, silicon oxide layers. At the end of the fabrication process, the silicon dioxide is chemically removed, thereby "releasing" the polycrystalline silicon layers such that are movable, as desired. The nominal spacing and thickness of layers is as follows. The first layer, identified as "Poly 0," is the ground plane layer of polysilicon having a nominal thickness of 0.3 microns. The next layer, "Poly 1," has a thickness of 1 micron. The nominal separation distance between Poly 1 and Poly 0 is 2 microns. The next layer, "Poly 2," has a nominal thickness of 1.5 microns and has a nominal separation distance of 0.5 microns from Poly 1. "Poly 3," which is the next layer, has a nominal thickness of 2.25 microns and a nominal separation distance of 2 microns from Poly 2. Finally, "Poly 4" has a nominal thickness of 2.25 microns and a nominal separation distance of 2 microns from Poly 3.

By way of example, in one embodiment of the fabrication of energy extraction apparatus **500** of FIG. 6 via the SUMMit V process, the Poly 3 layer will be used to fabricate plate **524**, the Poly 2 layer will be used for plate **522**, the Poly 1 layer will be used for plate **520** and the poly 0 layer will be used to fabricate plate **518**. Since only three "mechanical" layers are required for the apparatus of FIG. 6, the Poly 4 layer is not used. To immobilize plates **524** and **520**, layer thickness can be increased or, alternatively, braced, as appropriate.

Many other MEMS foundries are available for the fabrication of a stacked structure such as apparatus **500**. Those skilled in the art will know of such foundries and be able to suitably select one by matching their capabilities to the fabrication requirements of the device.

Radiation source **540** is advantageously formed separately from the stack of plates **518**, **520**, **522** and **524** according to well-known methods as is appropriate for the particular physical configuration of the radiation source (*e.g.*, laser, *etc.*). Electrical elements (*e.g.*, switch **538**, the wire traces, *etc.*) can be fabricated during stack formation as part of a surface micromachining process, or fashioned separately therefrom by standard processing techniques. The various elements are then appropriately packaged to form the complete energy extraction device **500**.

Before carrying out method step **302**, switch **538** is closed and a potential difference V_b is applied to the plates while plate **522** is at a distance s_D from the plate **520**. For pedagogical purposes, this state, which corresponds to point D in FIG. 2, is considered to be a state of mechanical equilibrium for the system.

FIG. 6 depicts transducer **500** at the completion of method step **302** (*i.e.*, at the completion of state change **202**), which corresponds to point A in FIG. 2. Recalling the earlier description, step **302** requires altering a physical factor Y_i. In the illustrative embodiments, this step is performed by activating radiation source **540**. Radiation source **540** is advantageously tuned to the ionization level of impurities in plates **520** and **522**. As a consequence, illuminating the facing sides **520a** and **522a** of respective plates **520** and **522** causes an increase in the concentration of free charge carriers in plates **520** and **522**, and, hence, an increase in the Casimir force.

The illumination is advantageously slowly increased so that the increase in the Casimir force occurs as a series of very small changes. According to engine cycle **200**, plate **522** is substantially stationary as the Casimir force is increased in step **302**. But as the Casimir force increases, there will be a tendency for plates **520** and **522** to be drawn closer together. To counteract this tendency, the electrostatic force between plates **524** and **522** is increased by small increases in potential V_b. Thus, there is a flow of charge from power supply **534** toward transducer **500**, as indicated by the flow of current toward the positive electrode of the power supply **534**. At the completion of step **302**, radiation source **540** remains on but the intensity of illumination is now held constant.

FIG. 7 depicts transducer **500** at the completion of method step **304** (*i.e.*, the end of state change **204**), which corresponds to point ***B*** in FIG. 2. As depicted in FIG. 7, plate **522** has moved closer to plate **520**. This decrease in distance between plates **522** and plate **520** increases the Casimir force. To move plate **522** closer to plate **520**, the voltage delivered by power supply **534** is slightly decreased. But, to maintain plate **522** in *quasi*-static equilibrium, charge continues to flow as distance s between plates **522** and **520** decreases until it reaches spacing s_B.

FIG. 8 depicts transducer **500** at the completion of method step **306** (*i.e.*, the end of state change **206**), which corresponds to point ***C*** in FIG. 2. As will be recalled, in step **306**, distance s between the plates **522** and **520** is held substantially constant while the altered property is advantageously returned to its initial condition. In the illustrated embodiment, step **306** is effected by decreasing illumination from radiation source **540** so that the free carrier concentration, and hence the Casimir force, decrease.

Since the Casimir force decreases as a result of step **306**, but the distance between the plates is held substantially constant, excess charge must be drained from plates **524** and **522**. The excess charge is drained since, if it were not, plate **522** would be drawn toward plate **524** (because the mutual electrostatic attraction between plates **524** and **522** is now greater than the mutual attraction between plates **522** and **520** due to the Casimir force). As illustrated in FIG. 8, current flow reverses, and energy is returned to bi-directional power supply **534**.

FIG. 9 depicts transducer **500** at the completion of method step **308** (*i.e.*, at the end of state change **208**), which corresponds to point ***D*** in the cycle. In the present example, at point ***D***, transducer **500** has completed a cycle.

As illustrated in FIG. 9, in step **308**, plate **522** is moved away from plate **520**, advantageously returning to its original position. This is accomplished by slightly increasing the voltage delivered by power supply **534**. As the distance between plates **522** and **520** is increased, the Casimir force decreases. Additional charge is drawn off plates **524** and **522** to maintain quasi-static equilibrium. As in the previous step, charge is returned to power supply **534**.

In view of the foregoing description, it will be appreciated that illustrative cycle **200** can be described in terms of the cycling of two independent control variables, both of which affect the Casimir force. Thus, in a further illustrative embodiment of a method **600** in accordance with the present teachings (*see* FIG. 10), a first control variable that affects the Casimir force is cycled as per operation **602** and, in operation **604**, a second control variable that affects the Casimir force is cycled. Such cycling effects the state changes (*i.e.*, state changes **202**, **204**, **206** and **208** defining engine cycle **200**.

In the illustrative embodiments depicted herein, the first control variable alters a physical factor that affects the Casimir force, while the second control variable controls movements of the Casimir force-generating boundaries.

By way of example, in an embodiment in which the physical factor is the concentration of free charge carriers, the first control variable is, in three different illustrative embodiments: (1) an amount of illumination; (2) an amount of thermal radiation; and (3) an amount of injected charge.

In the illustrative embodiments, voltage is used as the second control variable. In particular, voltage is used to change the distance between the boundaries (*e.g.*, state changes **204** and **208**), or, alternatively, is used to prevent the boundaries from moving, when the first control variable is used to alter a physical parameter (*e.g.*, state changes **202** and **206**).

FIG. 11a depicts, figuratively, the cycling of the first and second control variables to effect desired state changes in engine cycle **200**. The first control variable ***CV1*** is cycled between a first value and a second value, and the second control variable ***CV2*** is cycled between a third value and a fourth value. Generally, the cycle of each control variable is described by some function $F_N(T)$:

$$[10] \qquad \boldsymbol{CV1} = F_1(T); \text{ and}$$

$$\boldsymbol{CV2} = F_2(T).$$

The cycling of the two control variables is not necessarily expected to define the circular shape depicted in FIG. 11a or any of the shapes shown in FIGS. 11b – 10e. Such plots are illustrative and are provided simply as indication of some of the many possible ways in which first control variable ***CV1*** and a second control variable ***CV2*** may cycle to accomplish the desired state changes.

In FIGS. 11a – 11e, the first and second control variables are cycling with the same repetition rate (*i.e.*, at the same frequency). In other embodiments, the control variables cycle with different repetition rates. The plots describing the cycling of the control variables in embodiments in which the repetition rates differ will be relatively complex functions.

In the illustrative embodiments, energy transformation system **532** is physically configured to store energy accessed via the Casimir force-generating plates, after transformation, as electrical energy in bi-directional power supply **534**. In this configuration, energy extraction apparatus **500** is practicing operation **310A** of method **300**. In another embodiment (not shown), the same method step is practiced, but apparatus **500** includes separate power source and power storage (*i.e.*, for receiving transformed energy) facilities.

In another embodiment of method **300**, operation **310B** is practiced wherein extracted energy is delivered to a consumer of electrical energy for use thereby. In some embodiments, the energy is delivered from storage, such that, with minor modification (*i.e.*, appropriate electrical connnection to the electrical consumer), the physical configuration of the energy transformation system **532** depicted in FIGS. 6-9 may suitable be used.

In yet an additional embodiment of operation **310B**, energy is delivered to a consumer as it becomes available from the method steps, such that energy transformation system **532** must be suitably modified by changes that are within the capabilities of those skilled in the art. This embodiment is depicted in the simplified schematic of FIG. 11 wherein energy extraction device **500** is electrically connected to electrical device **650**. Energy accessed via Casimir force-generating boundaries that is transformed to electrical energy is then used to power device **650**.

In accordance with operation **310C** of yet a further embodiment of illustrative method **300**, energy accessed via Casimir force-generating boundaries is used to mechanically actuate a device. In one embodiment, this is accomplished by operatively linking the movable Casimir force-generating boundary to the device so that the device is actuated by movement of the movable boundary. Such an embodiment will again require modifications to energy transformation system **532** that are within the capabilities of those skilled in the art.

For example, as depicted in the simplified schematic of FIG. 12, energy extraction device **500** is operatively engaged to micro-mechanical device **754** by linkage **752**. Micro-mechanical device **754** functions as an optical switch wherein shutter **758** is moved into or out of the path of an optical signal (not shown) traveling through core **766** of fiber **760**. Shutter **758** moves responsive to movements of plate **522** along direction **756**. Movements of plate **522** responsive to the present method are transmitted to shutter **758** via linkage **752**.

When shutter **758** is in the path of an optical signal (*i.e.*, when the shutter intersects core **766**), further propagation of the optical signal is halted. When shutter **758** is out of the path of the optical signal, the signal passes unimpeded.

In the illustrative embodiments described above, radiation is used to change a property of at least one of two interacting surfaces (although there are other ways to effect such change, such as, for example, charge injection). In further embodiments, radiation can be used to change a property of a *particle* interacting with a surface. In fact, the latter can be viewed as the limit of the former when the second surface is an extremely rarified layer of neutral atoms. Consequently, surface-surface forces can be explained as simply a large-scale manifestation of the atom-surface force.

Further illustrative embodiments provide methods and apparatuses by which a particle is accelerated or decelerated based, in the main, on particle-surface interactions (although the following embodiments are not limited to such particle-surface interactions). Particles traveling away from a surface are made to travel at either a higher or lower speed than that with which they approached the surface. Particle velocity is changed by prompting the particles to undergo atomic transitions during their interaction with the surface.

In the description that follows, reference is made to concepts such as the van der Waals force, the Casimir-Polder force, the Bohr radius, the quantum number and the like. Such terms will be used without definition or description due to their well-defined meanings and the familiarity of those skilled in the art with such concepts.

In accordance with some embodiments of the present teachings, to accelerate a particle, such as an atom that is in its ground state, the particle is "excited" (*i.e.*, transitions to a higher energy level) on its way to a close approach with a surface. In one embodiment, this excitation is accomplished using a laser. When the particle is at or near its closest approach to the surface, it is then advantageously prompted to return to its ground state.

During the approach to the surface in the excited state, the van der Waals force between the particle and the surface is quite high. After returning to the ground state, the van der Waals force between the particle and the surface is substantially reduced. This reduced attraction results in a significant increase in particle velocity.

To decelerate a particle, such as an atom in its ground state, the particle is excited, but that excitation occurs just *after* closest approach to the surface. Thus, the outbound particle, now in an excited state, experiences a much higher van der Waals force with the surface than when it was inbound toward the surface at the ground state. This increased attraction significantly *decreases* particle velocity.

Underlying the present invention is the discovery that by prompting a particle to undergo an atomic transition during its interaction with the surface, its outgoing speed (*i.e.*, speed as it moves away from a surface) can be changed relative to its incoming speed. The method is consistent with the conservation of energy principle.

The methods and apparatuses described herein are an improvement on an experiment known as the "Raskin-Kusch experiment," which has been used for the last forty years to investigate van der Waals forces. In particular, to measure atom-surface interactions, an atomic beam is directed near a conducting cylindrical surface and the deflection of the atoms from the surface due to van der Waals forces is measured.

The Raskin-Kusch experiment does not cause particles, such as atoms, to undergo an atomic transition during their interaction with the surface. Since the particles in the Raskin-Kusch experiment do not undergo an atomic transition during their interaction with the surface, they emerge from the interaction with the surface with a changed direction but with *no change in speed.* The constant speed is due to the fact that the van der Waals force behaves as a conservative force. As such, when a particular atom is at a large distance from the surface, its speed is the same as it was on the incoming leg of the trajectory.

In most embodiments of the present invention, the particle that is accelerated will be quite small. Examples of small particles used in various embodiments, include, without limitation, neutral atoms, neutral molecules, and neutral elementary particles. But the present methods apply irrespective of size. For example, in some embodiments, micro-scale neutral specks of dust are accelerated/decelerated. And, on a much more macroscopic scale, a neutral ball one-foot in diameter is accelerated/decelerated in accordance with the present teachings. It will be understood, however, that the amount of acceleration/deceleration imparted to such macro-scale objects will be quite small compared to that imparted to atomic-sized particles. In general, the term "**particle**" includes all such sub-atomic-, atomic-, micro- and macro-scale objects.

The van der Waals and Casimir-Polder forces depend on the quantum state of the particle, for example, an atom, next to the surface of interest. In particular, van der Waals and Casimir-Polder forces are proportional to the second power of the Bohr radius of the atom. And, the Bohr radius is itself proportional to the second power of the principal quantum number, n, which describes in part the state of the atom. Therefore, van der Waals and Casimir-Polder forces are proportional to the fourth power of the principal quantum number:

[1] $$\text{force} \propto n^4$$

This dependence on the fourth power of n is an important ramification in the context of the present invention. Consider, for example, a "cold" particle, such as a cold atom. When cold, the particle is usually in its ground state, which, for an atom, corresponds to a principal quantum number $n = 1$. Consider an atom in an excited state having, for example, a principal quantum number $n = 10$. In such a case, the van der Waals force attracting the excited particle to the surface is, in accordance with expression [1], 10^4 or 10,000 times greater than when the particle is in its ground state.

As used herein, the term "**excite**" or "**excited**" refers to a particle that, due to the introduction of energy, is at a higher energy level than its ground state. In the particular case of an atom, an excited atom will have a principal quantum number that is greater than 1.

FIG. 14 depicts an embodiment of a particle accelerator **800** in accordance with the illustrative embodiment of the present invention. Particle accelerator **800** comprises particle source **802**, collimator **806**, particle exciter **814**, surface **816** and optional particle de-exciter **820**, interrelated as shown.

Particle source **802** contains the particles that will be accelerated by accelerator **800**. Particle source **802** can be embodied as any of a variety of well-known devices/systems, such as, without limitation, an oven containing a hot gas or an apparatus for atom trapping and cooling. In the illustrative embodiment, particle source **802** includes orifice **804** that allows at least some of the particles in particle source **802** to escape. In some embodiments, orifice **804** is a hole that is about 1 millimeter in diameter.

Escaped particles **801** encounter collimator **806**. Collimator **806** provides a highly directional beam of particles **803**, the direction of which is toward surface **816**. Collimator **806** is realized, in the illustrated embodiment, as two plates **808** and **810** that are spaced from one another such that slit **812** is defined therebetween. Other arrangements that provide a slit or other orifice operable to collimate the escaped particles **801** may suitably be used in place of plates **808** and **810**.

In the illustrative embodiment, at least some of collimated particles **803** are excited by particle exciter **814**. Upon leaving particle source **802** and passing collimator **806**, particles **801/803** are at their ground state, $|\mathbf{A}\rangle$. Particle exciter **814** excites at least some of particles **803** to a higher energy state $|\mathbf{B}\rangle$. In some embodiments, particle exciter **814** is a source of electromagnetic radiation. And, in one specific embodiment, particle exciter **814** is a tunable laser that is advantageously tuned to the transition energy of the particles **803**.

Excited particles **805** (and unexcited particles) approach surface **816**. The surface is advantageously a material capable of being polished to a high degree of smoothness, such as, for example, gold. In various embodiments, surface **816** comprises a dielectric, a semiconductor and a conductor.

In the illustrative embodiments, surface **816** has a cylindrical shape, but in other embodiments, surfaces having arbitrary shapes, including irregular shapes, are suitable used. Regardless of its specific geometry, surface **816** advantageously allows a particle to make a "**minimum distance**" or "**closest**" approach (to the surface) and then allows the particle to escape without contact. For example, a spherical surface or cylindrical surface facilitates such a minimum distance approach or closest approach since there will be one location on the surface that protrudes further than others from the perspective of the particle's trajectory. That point is the location of the minimum distance or closest approach. Since a flat surface (*e.g.*, a plate) does not readily allow for a minimum distance approach and escape, it should not be used.

Recalling expression [1], excited particles **805** will experience a substantially larger van der Waals attraction to surface **816** than unexcited particles. At or near closest approach **818**, excited particles **805** decay back to their ground state with the emission of photon γ. Decay to the ground state is caused by spontaneous decay, or via stimulated decay using optional particle de-exciter **820**. The time for spontaneous decay can be predicted by those skilled in the art, so that spontaneous decay can be relied on to cause the required transition at or near closest approach.

In some embodiments, particle de-exciter stimulates decay by injecting additional energy into excited particles **805**. In some embodiments, particle de-exciter **820** is a tunable laser.

After decay to the ground state, the van der Waals attraction between outbound decayed particles **807** and surface **816** is much less the van der Waals attraction between inbound excited particles **805** and surface **816**. As a consequence, particles **807** will be traveling much faster after the interaction with surface **816** than they were when they first left particle source **802**. The trajectory of particles **807** can be calculated using classical mechanics (*i.e.*, scattering theory).

In the context of the present invention, the decay must occur "near closest approach" to the surface since van der Waals forces fall off rapidly with distance:

[2] $$\text{force} = -K / R^4$$

where: K is a constant; and
R is the distance between the particle and the surface

As used in this *Specification*, the term "**near closest approach**" or "**near minimum distance,**" "**near minimum approach**" or "**during interaction**," when used in conjunction with a transition to or from the ground state, means that the particle is within a few micrometers (*e.g.*, less than 5 micrometers), and advantageously within a few hundred angstroms of closest approach.

Note that the efficiency of the apparatus **800** is at its maximum when the transition occurs at closest approach. To the extent the transition occurs "near" closest approach, some amount of efficiency is lost. This is true whether the transition occurs near but before closest approach or near but after closest approach.

This result — this increase in speed — is not in conflict with the principle of conservation of energy. In particular, the energy of the electromagnetic radiation emitted by particle **805** as it decays is actually less than it originally absorbed. And the difference between the emitted energy and the absorbed energy is exactly equal to the increase in kinetic energy of the particle after its closest approach to surface **816**.

With minor modifications that are described below in conjunction with FIG. 15, the apparatus and method described above is used to decelerate a particle. FIG. 15 depicts a particle decelerator in accordance with the present teachings.

Like particle accelerator **800**, particle decelerator **900** comprises particle source **802**, collimator **806**, particle exciter **814** and surface **816**, interrelated as shown. In decelerator **900**, however, particle exciter **814** excites particles following but near closest approach **818**, rather than before closest approach as in particle accelerator **800**.

As in particle accelerator **800**, ground state particles **801** exit particle source **802** through orifice **804** and are collimated by collimator **806**. Collimated ground state particles **803** approach surface **816**. After but near closest approach **818** to surface **816**, at least some of particles **803** are excited by particle exciter **814**. In some embodiments, particle exciter **814** is a source of electromagnetic radiation, such as, without limitation, a tunable laser that is advantageously tuned to the transition energy of the particles **803**.

The van der Waals force between excited particles **805** and surface **816** is greater than the van der Waals force between inbound ground state particles **803** and surface **816**. As a consequence, outbound excited particles **805** are moving substantially more slowly than inbound particles **803**.

Excited particles **805** decay, at some point, back to their ground state (particle **807**) with the emission of photon γ. Since the decay occurs far from closest approach, such decay has a *de minimis* effect on particle speed.

FIG. 16 depicts an illustrative method **1000** for accelerating particles, either positively (*i.e.*, increasing speed) or negatively (*i.e.*, decreasing speed), in accordance with the present teachings. In accordance with operation **1002**, particles are directed toward a surface, such as surface **816** (*see* FIGS. 14 and 15). In operation **1004**, at least some of the particles are excited to a higher energy level.

To function as a particle accelerator, operation **1004** (*i.e.*, exciting particles) is performed before closest approach with the surface. To cause deceleration, operation **1004** is performed after but near closest approach with the surface.

In some embodiments, method **1000** includes operation **1006** wherein excited particles are de-excited, such as by injecting more energy into the particles.

FIG. 17 depicts an alternate embodiment of a method **1100** for accelerating particles, either positively (*i.e.*, increasing speed) or negatively (*i.e.*, decreasing speed), in accordance with the present invention. In accordance with operation **1102**, particles are directed toward a surface, such as surface **816** (*see* FIGS. 14 and 15). In operation **1104**, at least some of the particles are prompted into atomic transitions during their interaction (*i.e.*, near closest approach) with the surface.

When accelerating particles, operation **1104** comprises, in some embodiments, exciting particles and then de-exciting particles, such as by the addition of energy. The step of de-exciting occurs near closest approach. When decelerating particles, operation **1104** comprises exciting the particles after but near closest approach.

Further embodiments of a method **1200** for particle acceleration are described below in conjunction with FIG. 18.

In accordance with operation **1202** of method **1200**, particles are directed to closest approach with a surface. In operation **1204**, when the particle is near closest approach to the surface, a physical factor of the surface that affects a Casimir force between the particle and the surface is altered. Physical factors affecting the Casimir force were mentioned earlier in this *Specification* and include, without limitation, the concentration of free charge carrier in the surface and the dielectric properties of the material comprising the surface.

The material(s) comprising the surface are suitably selected as a function of the altered physical factor. For example, in an embodiment wherein the altered physical factor is the concentration of free charge carriers, the material is advantageously a semiconductor or compound semiconductor. Illustrative semiconductors (for embodiments wherein the altered physical factor is the concentration of free charge carriers) include, without limitation, silicon (Si), germanium (Ge), and compound semiconductors such as, without limitation, gallium arsenide (GaAs), indium gallium arsenide (InGaAs) and indium antimonide (InSb).

Moreover, in some embodiments, the surface comprises doped semiconductors and doped compound semiconductors, including, without limitation, phosphorus-doped silicon and indium antimonide that includes naturally occurring impurities. In some embodiments, dopants are selected based on their relative ease of ionization.

In embodiments in which the altered physical factor is the concentration of free charge carriers, alteration is effected in a variety of ways, including, without limitation, illuminating the surface with a laser, heating the surface, and injecting charge into the surface.

An example of the operation of method **1200** is now described in an embodiment in which the altered physical factor is the concentration of free charge carriers and the manner in which the concentration is altered is by illuminating the surface with a laser.

In an embodiment of method **1200** in which particles are accelerated, the surface is illuminated by laser before particles are near closest approach. As the particle is near closest approach, it is subjected to a relatively higher force of attraction due to a Casimir force than if the surface was not illuminated. This is due, in this embodiment, to the increase in the concentration of free charge carriers. At closest approach, or after but still near closest approach, illumination is decreased or terminated. This decreases the Casimir force so that particle departs at increased velocity.

To decelerate particles, the timing of illumination is simply reversed from the acceleration case. That is, the laser is turned on at closest approach, or after, but near closest approach. The Casimir force will therefore be greater between the particle and the surface when it is outbound from closest approach such that the particle is decelerated.

It will be appreciated that due to the timing issues involved in method **1200**, particles must be delivered to the surface in a pulsed fashion. In other words, illustrative method **1200** can not be practiced using a continuous stream of particles.

In further embodiments, methods **1000** and **1200** can be used together, and methods **1100** and **1200** can be used together. In other words, in addition to, for example, illuminating a particle with a laser to cause a transition, the surface can be illuminated, *etc.* to use the Casimir force to accelerate or decelerate the particle, as well.

The present methods and apparatuses find utility in a variety of applications including, for example, particle heating and cooling devices, micro-propulsive systems, sensors and energy conversion devices.

I claim:

1. A method comprising:

altering, from a first value to a second value, a physical factor that affects a Casimir force between a first Casimir force-generating boundary and a second Casimir force-generating boundary;

changing a spacing between said first Casimir force-generating boundary and said second Casimir force-generating boundary from a first distance to a second distance;

altering said physical factor from said second value to a third value; and

changing said spacing from said second distance to a third distance.

2. The method of claim 1 wherein said third value is equal to said first value.

3. The method of claim 1 wherein said third distance is equal to said first distance.

4. The method of claim 1 wherein said step of altering comprises altering a concentration of free charge carriers in at least one of said first Casimir force-generating boundary and said second Casimir force-generating boundary.

5. The method of claim 4 wherein:

said step of altering, from a first value to a second value, comprises illuminating said at least one Casimir force-generating boundary;

said step of altering from said second value to a third value, comprises reducing said illumination.

6. The method of claim 5 wherein:

said step of changing a spacing comprises decreasing said distance between said first Casimir force-generating boundary and said second Casimir force-generating boundary; and

said step of changing said spacing comprises increasing said distance between said first Casimir force-generating boundary and said second Casimir force-generating boundary.

7. The method of claim 1 wherein said step of altering comprises altering a temperature of at least one of said first Casimir force-generating boundary and said second Casimir force-generating boundary.

8. The method of claim 1 further comprising storing energy accessed via said first Casimir force-generating boundary and said second Casimir force-generating boundary.

9. The method of claim 1 wherein at least one of said first Casimir force-generating boundary and said second Casimir force-generating boundary is movable, said steps of changing further comprising moving an element of a micromechanical device that is operatively coupled to said at least one movable Casimir force-generating boundary.

10. The method of claim 1 further comprising delivering, to an electrical device, energy accessed via said first Casimir force-generating boundary and said second Casimir force-generating boundary.

11. A method comprising:

adding energy to at least one of two spaced Casimir force-generating boundaries;

decreasing a separation between said two spaced Casimir force-generating boundaries to a first distance;

decreasing a rate by which said energy is added to said at least one Casimir force-generating boundary; and

increasing said distance between said two spaced Casimir force-generating boundaries to a second distance.

12. The method of claim 11 wherein said step of adding energy comprises preventing said two spaced Casimir force-generating boundaries from moving relative to one another.

13. The method of claim 11 wherein said step of adding energy comprises illuminating said at least one Casimir force-generating boundary.

14. The method of claim 11 wherein said step of adding energy comprises heating said at least one Casimir force-generating boundary.

15. The method of claim 11 wherein said step of adding energy comprises adding said energy in a series of small increments, wherein a rate by which said energy is added is successively increased.

16. The method of claim 15 wherein said step of decreasing a distance further comprises holding said rate constant.

17. The method of claim 11 wherein said step of decreasing a rate further comprises maintaining said first distance.

18. The method of claim 11 wherein said step of decreasing a rate by which said energy is added comprises stopping the addition of energy.

19. A method comprising:

drawing a first boundary toward a second boundary, wherein physical factors affecting a Casimir force that arises between said first boundary and said second boundary have a first set of values; and

pulling said first boundary and said second boundary away from one another when said physical factors have a second set of values;

wherein said first set of values results in a greater magnitude of said Casimir force than said second set of values for any given separation between said first boundary and said second boundary.

20. The method of claim 19 wherein said step of drawing comprises imparting said first set of values to said physical factors by illuminating at least one of said first boundary and said second boundary.

21. The method of claim 20 wherein said step of pulling comprises reducing an intensity of said illumination.

22. The method of claim 19 wherein said step of drawing comprises imparting said first set of values to said physical factors by applying heat to at least one of said first boundary and said second boundary.

23. The method of claim 22 wherein said step of pulling comprises reducing said applied heat.

24. The method of claim 19 further comprising the step of storing energy accessed via said first boundary and said second boundary.

25. The method of claim 19 further comprising delivering to an electrical device energy accessed via said first Casimir force-generating boundary and said second Casimir force-generating boundary.

26. A method comprising:

cycling a first control variable that affects a Casimir force between a first Casimir force-generating boundary and a second Casimir force-generating boundary, wherein said first control variable is cycled between a first value and a second value; and

cycling a second control variable that affects said Casimir force between said first Casimir force-generating boundary and said second Casimir force-generating boundary, wherein said second control variable is cycled between a third value and a fourth value.

27. The method of claim 26 wherein said first control variable affects a physical factor that affects said Casimir force.

28. The method of claim 27 wherein said physical factor is a concentration of free charge carriers in at least one of said first Casimir force-generating boundary and said second Casimir force-generating boundary.

29. The method of claim 26 wherein said first control variable is an illumination of at least one of said first Casimir force-generating boundary and said second Casimir force-generating boundary.

30. The method of claim 26 wherein said second control variable is a voltage that is operative to change a distance between said first Casimir force-generating boundary and said second Casimir force-generating boundary.

31. The method of claim 26 wherein said first control variable and said second control variable are cycled at a same repetition rate.

32. A method comprising:

altering a value of a physical factor that affects a Casimir force between a first Casimir force-generating boundary and a second Casimir force-generating boundary; and

changing a separation distance between said first Casimir force-generating boundary and said second Casimir force-generating boundary from a first distance to a second distance.

33. The method of claim 32 wherein said step of altering comprises maintaining said separation distance at said first distance.

34. The method of claim 32 wherein said step of changing comprises maintaining said value of said physical factor constant.

35. A method comprising:

increasing a Casimir force by altering a physical factor of a first Casimir force-generating boundary; and

increasing said Casimir force by decreasing a distance between said first Casimir force-generating boundary and a second Casimir force-generating boundary.

36. The method of claim 35 further comprising decreasing said Casimir force by re-altering said physical factor.

37. The method of claim 36 further comprising decreasing said Casimir force by increasing said distance between said first Casimir force-generating boundary and said second Casimir force-generating boundary.

38. An apparatus comprising:

A first Casimir force-generating boundary and a second Casimir force-generating boundary that are spaced apart by a distance from one another, wherein said distance is changeable;

an energy transformation system that operatively engages at least one of said first Casimir force-generating boundary and said second Casimir force-generating boundary, wherein said energy transformation system comprises:

a first device that is operative to alter a physical factor of at least one of said first Casimir force-generating boundary and said second Casimir force-generating boundary; and

a second device that is operative to change said distance, or prevent said distance from changing, while said first device alters said physical factor.

39. The apparatus of claim 38 wherein said first device comprises an illumination source that is operative to illuminate said at least one of said first Casimir force-generating boundary and said second Casimir force-generating boundary.

40. The apparatus of claim 38 wherein said second device is a power supply.

41. The apparatus of claim 38 wherein:

a second side of said first Casimir force-generating boundary is conductive;

a second side of said second Casimir force-generating boundary is conductive; and

said power supply is electrically connected to:

said second side of said first Casimir force-generating boundary; and

said second side of said second Casimir force-generating boundary.

42. The apparatus of claim 41 further comprising:

a first conductive plate disposed in spaced relation and proximal to said second side of said first Casimir force-generating boundary; and

a second conductive plate disposed in spaced relation and proximal to said second side of said second Casimir force-generating boundary.

43. The apparatus of claim 42 wherein said power supply is electrically connected to said first conductive plate and said second conductive plate.

44 The apparatus of claim 43 wherein:

said second side of said first Casimir force-generating boundary and said second side of said second Casimir force-generating boundary are both at a first voltage; and

said first conductive plate and said second conductive plate are both at a second voltage.

45. The apparatus of claim 38 wherein at least one of said first Casimir force-generating boundary and said second Casimir force-generating boundary comprises a material selected from the group consisting of semiconductors and compound semiconductors.

46. The apparatus of claim 45 wherein said material is doped with an impurity to increase, relative to said material without said impurity, a concentration of free charge carriers on exposure to radiation.

47. An apparatus comprising:

a first Casimir force-generating boundary and a second Casimir force-generating boundary that are spaced by a distance from one another, wherein said distance is changeable;

a first capacitive structure comprising a first conductive plate spaced from said first Casimir force-generating boundary;

a second capacitive structure comprising a second conductive plate spaced from said second Casimir force-generating boundary; and

a device that is operative to alter a physical factor of at least one of said CFG boundaries.

48. The apparatus of claim 47 wherein said device is a source of electromagnetic radiation.

49. The apparatus of claim 47 wherein said device is a source of thermal radiation.

50. The apparatus of claim 47 further comprising a charge source that is electrically connected to said first Casimir force-generating boundary and said second Casimir force-generating boundary, and to said first conductive plate and said second conductive plate.

51. The apparatus of claim 47 wherein:

a second side of said first Casimir force-generating boundary that faces said first conductive plate is conductive;

a first side of said first Casimir force-generating boundary that faces a first side of said second Casimir force-generating boundary is not conductive;

a second side of said second Casimir force-generating boundary that faces said second conductive plate is conductive; and

said first side of said second Casimir force-generating boundary is not conductive.

52. The apparatus of claim 47 wherein at least one of said first Casimir force-generating boundary and said second Casimir force-generating boundary is operatively connected to a micro mechanical device.

52. The apparatus of claim 52 wherein the at least one Casimir force generating boundary that is operatively connected to said micromechanical device is connected thereto via a mechanical linkage.

54, The apparatus of claim 47 wherein said apparatus is electrically connected to a consumer of electricity.

55. A method comprising:

directing a plurality of particles toward a surface, wherein said surface is physically configured to allow said particles to approach said surface to a minimum distance but not contact said surface; and

exciting at least some of said particles.

56. The method of claim 55 wherein said step of directing further comprises collimating said plurality of particles.

57. The method of claim 55 wherein said step of exciting comprises exciting said at least some particles before closest approach to said surface.

58. The method of claim 57 wherein said step of exciting comprises exposing said particles to electromagnetic radiation suitable for causing the excitation of said particles.

59. The method of claim 57 further comprising de-exciting at least some of said particles at or near closest approach to said surface.

60. The method of claim 59 wherein said step of de-exciting comprises exposing said particles to electromagnetic radiation suitable for causing decay to a ground state.

61. The method of claim 55 wherein said step of exciting comprises exciting said at least some particles after but near closest approach to said surface.

62. The method of claim 61 wherein said step of exciting comprises exposing said particles to electromagnetic radiation suitable for causing the excitation of said particles.

63. A method comprising:

directing a plurality of particles toward a surface, wherein said surface is physically configured to allow said particles to approach said surface to a minimum distance but not contact said surface; and

prompting at least some of said particles into atomic transitions during their interaction with said surface.

64. The method of claim 63 wherein said step of prompting further comprises:

exciting said at least some particles before approaching said minimum distance; and

de-exciting at least some particles of the excited particles at or near said minimum distance.

65. The method of claim 63 wherein said step of prompting further comprises exciting said at least some particles after but near said minimum distance.

66. A method comprising:
exciting a plurality of particles;
directing said plurality of particles to a closest approach to a surface; and
releasing a photon from at least some of said excited particles.

67. The method of claim 66 wherein said step of exciting occurs before said closest approach of said particles to said surface.

68. The method of claim 67 wherein said step of releasing a photon comprises releasing said photon at or near said closest approach to said surface.

69. The method of claim 66 wherein said step of exciting occurs after but near said closest approach of said particles to said surface.

70. An article comprising:.
a particle source;
a particle exciter to excite at least some particles exiting said particle source; and
a surface having a physical configuration suitable for allowing a minimum distance approach of said particles to said surface.

71. The article of claim 70 further comprising a collimator that collimates said particles exiting said particle source.

72. The article of claim 70 further comprising a particle de-exciter.

73. The article of claim 70 wherein said surface has a cylindrical shape.

74. The article of claim 70 wherein said particle exciter is a tunable laser.

75. The article of claim 70 wherein said particle exciter excites said some particles before said particles approach near minimum distance from said surface.

76. The article of claim 70 wherein said particle exciter excites said some particles after said some particles approach minimum distance, but near said minimum distance.

77. A propulsion device comprising:
a first electromagnetic energy source for exciting particles;
a surface; and
a second electromagnetic energy source for de-exciting particles.

78. The propulsion device of claim 77 wherein said first electromagnetic energy source is a laser.

79. The propulsion device of claim 77 further comprising a particle source.

80. The propulsion device of claim 79 wherein said particle source is outer space.

81. A method comprising altering a physical factor affecting a Casimir force between a surface and a particle when said particle is near closest contact with said surface.

82. The method of claim 81 wherein altering a physical factor comprises illuminating said surface.

83. The method of claim 82 wherein altering further comprises:
illuminating said surface before said particle is near closest contact;
decreasing said illumination when said particle is at closest contact, or after but near closest contact.

84. The method of claim 82 wherein altering further comprises illuminating said surface when said particle is at closest contact, or after but near closest contact.

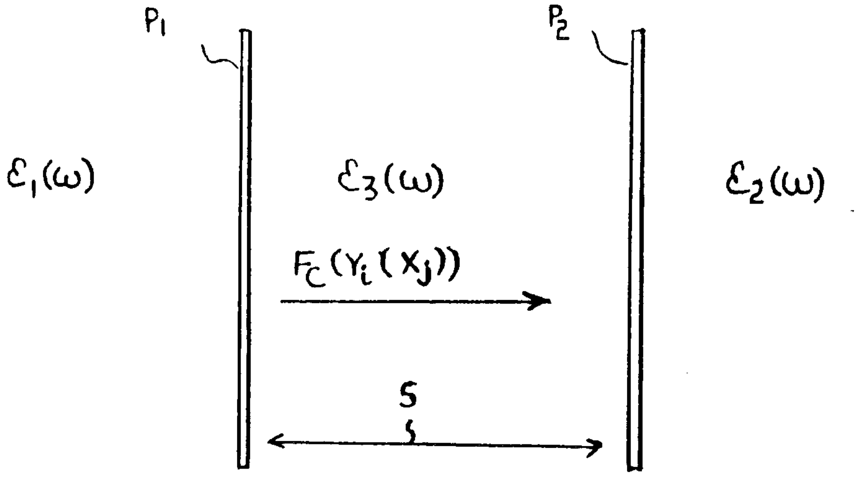


FIG. 1
PRIOR ART

FIG. 2

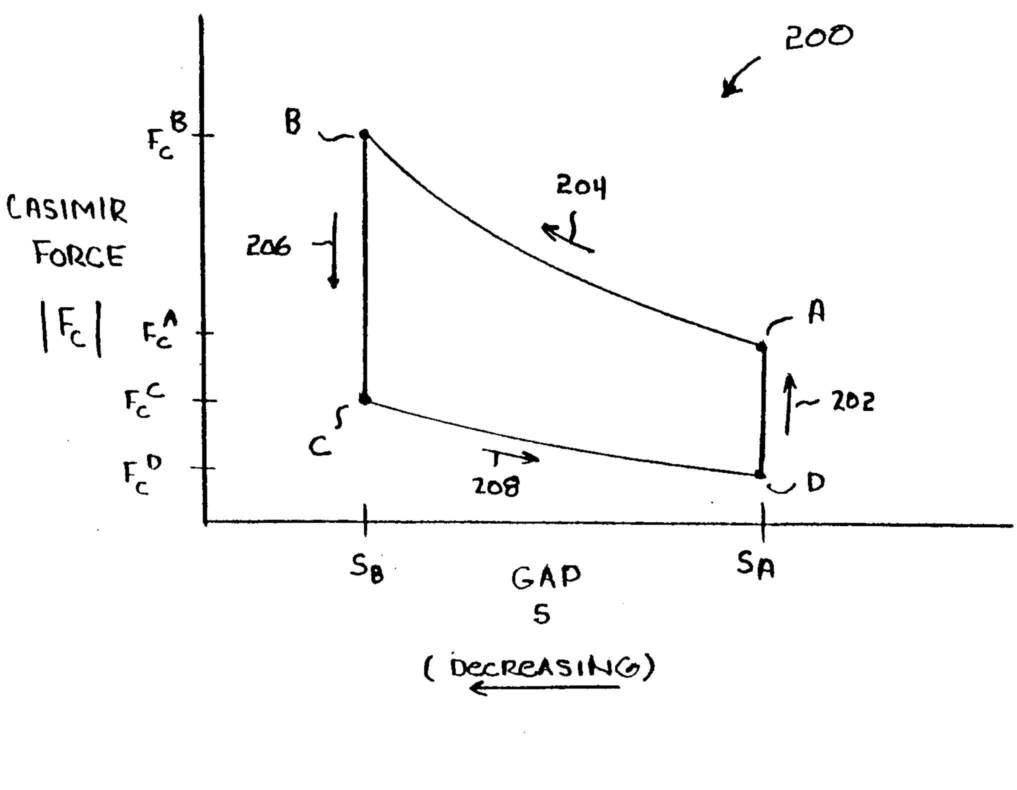


FIG. 3

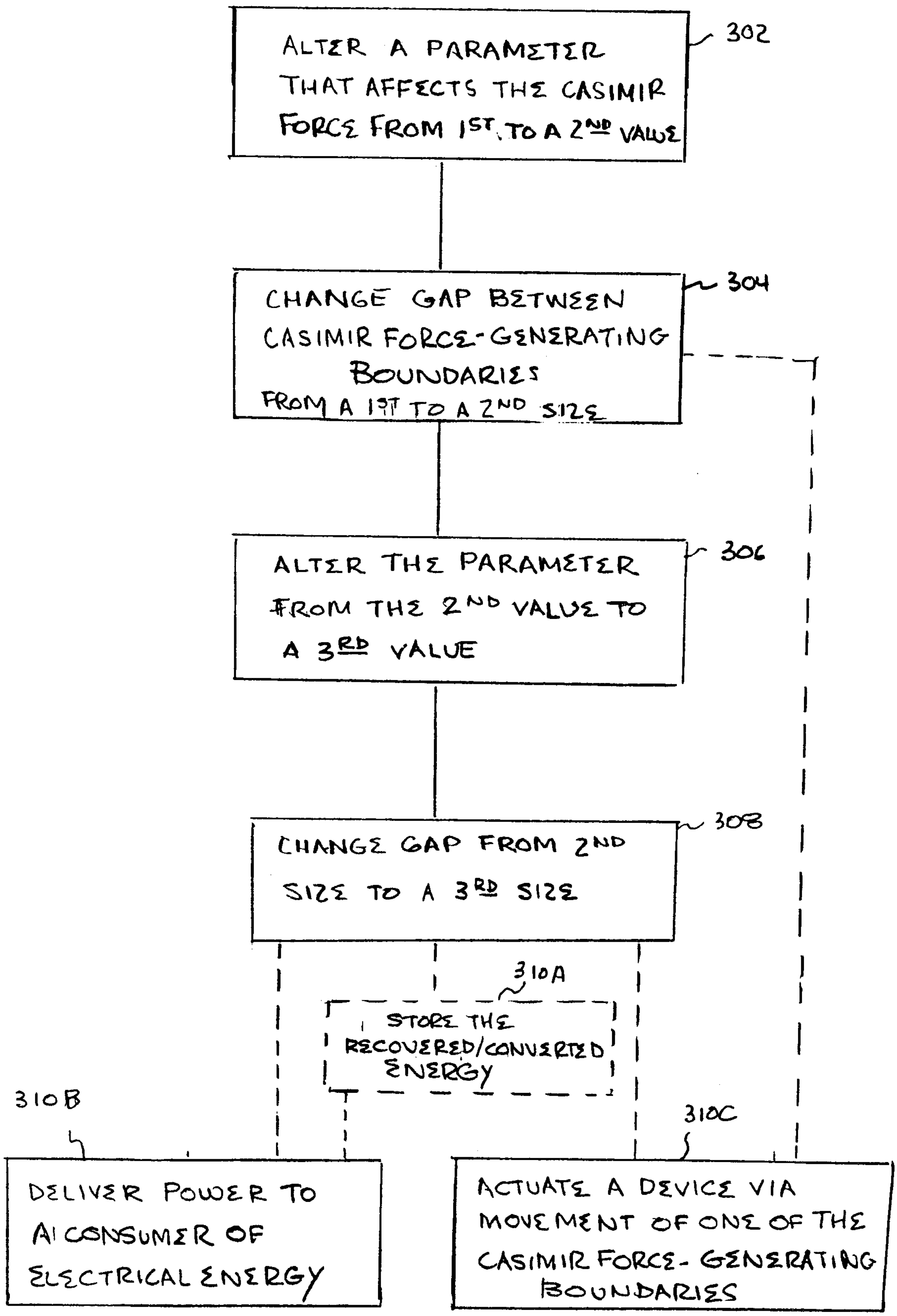
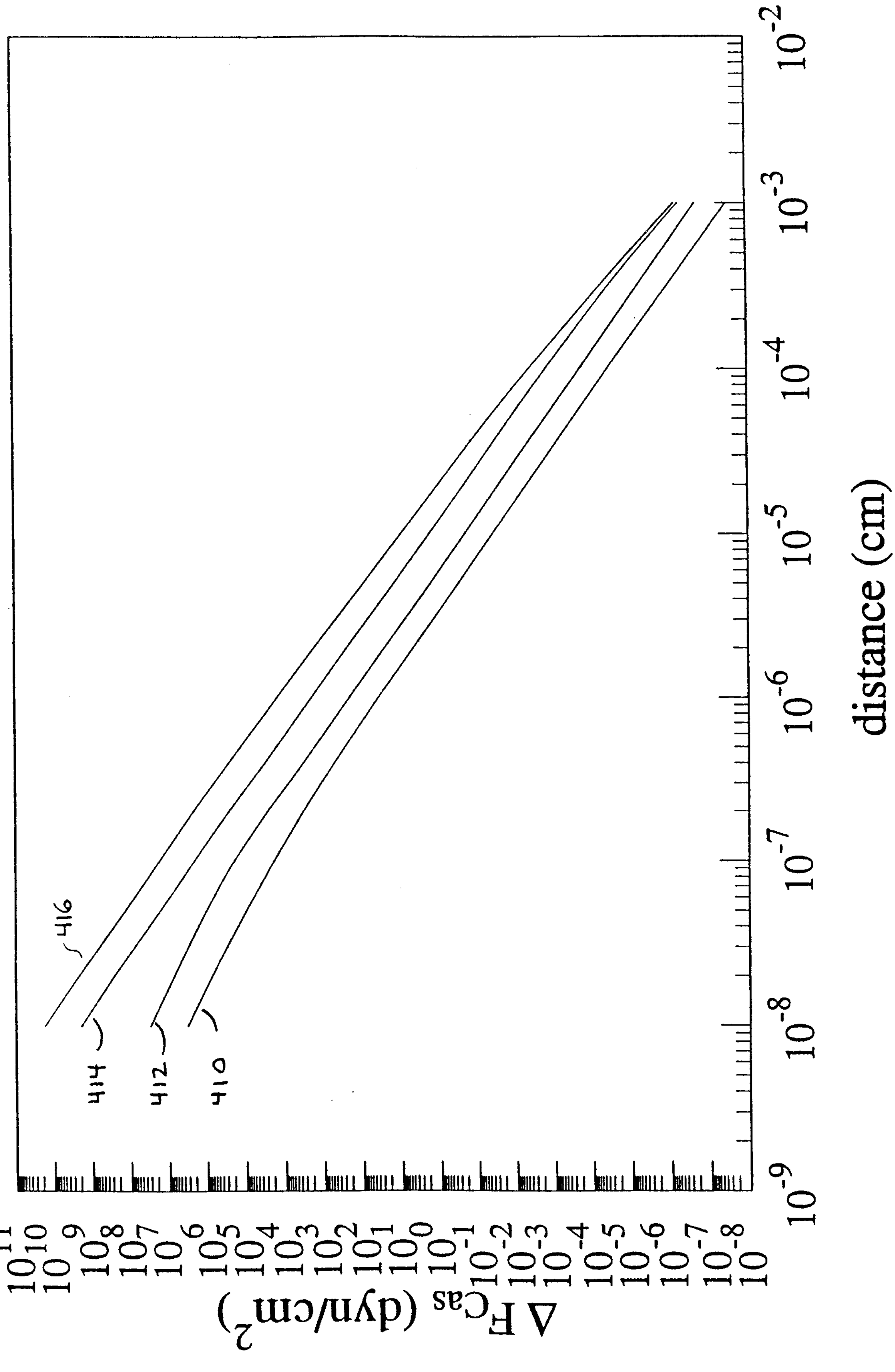

ALTER A PARAMETER THAT AFFECTS THE CASIMIR FORCE FROM 1ST TO A 2ND VALUE
302
CHANGE GAP BETWEEN CASIMIR FORCE-GENERATING BOUNDARIES FROM A 1ST TO A 2ND SIZE
304
ALTER THE PARAMETER FROM THE 2ND VALUE TO A 3RD VALUE
306
CHANGE GAP FROM 2ND SIZE TO A 3RD SIZE
308
310A
STORE THE RECOVERED/CONVERTED ENERGY
310B
DELIVER POWER TO A CONSUMER OF ELECTRICAL ENERGY
310C
ACTUATE A DEVICE VIA MOVEMENT OF ONE OF THE CASIMIR FORCE-GENERATING BOUNDARIES

FIG. 4


ΔF_Cas (dyn/cm^2)
distance (cm)
10^-9
10^-8
10^-7
10^-6
10^-5
10^-4
10^-3
10^-2
10^11
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
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10^-8
410
412
414
416

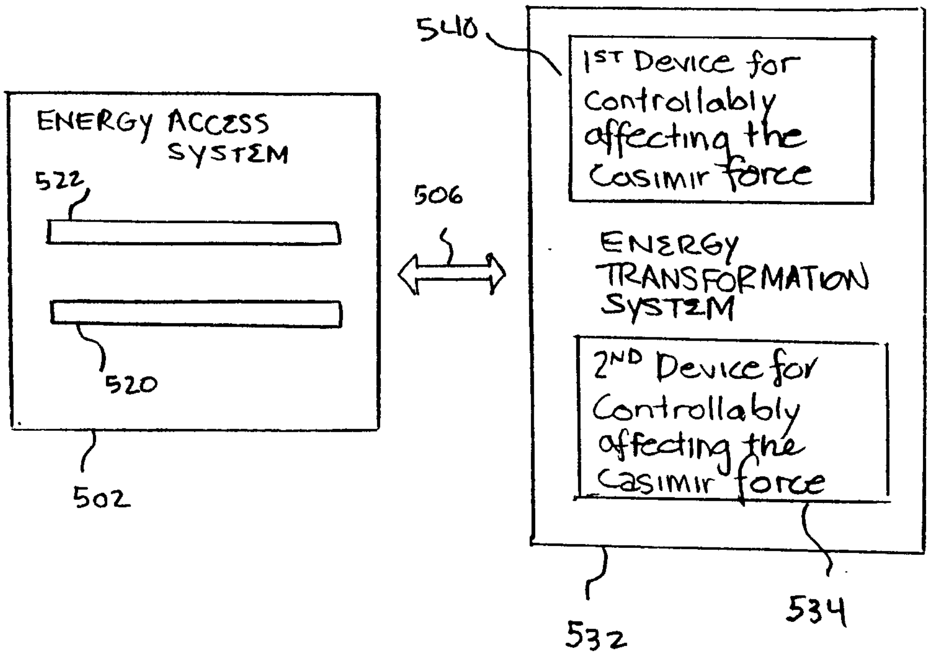
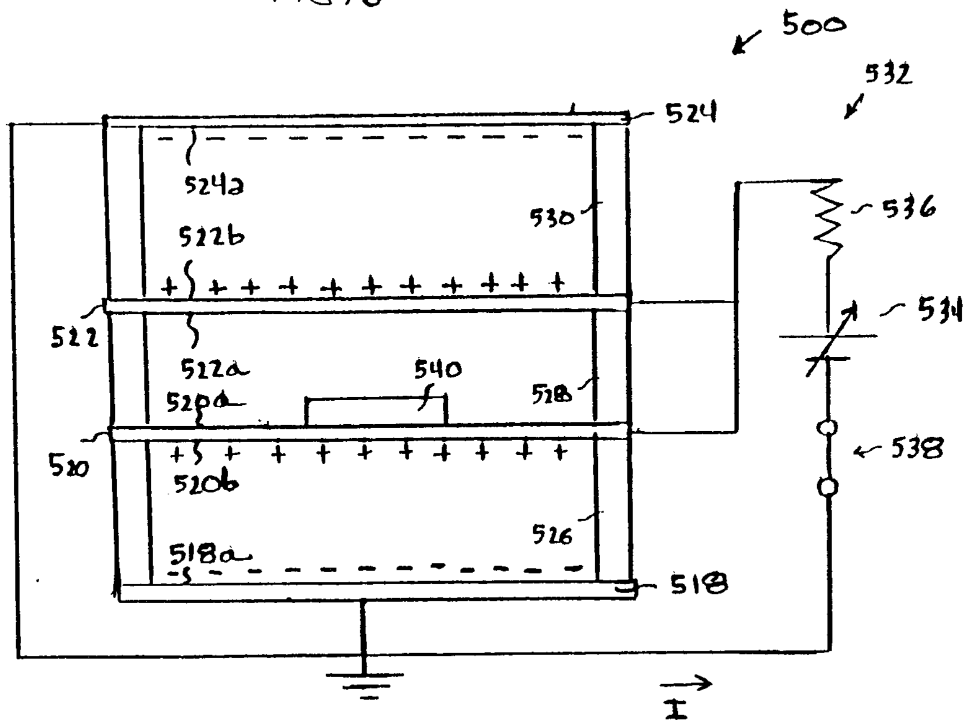

ENERGY ACCESS SYSTEM
522
520
502
506
540
1ST Device for Controllably affecting the Casimir force
ENERGY TRANSFORMATION SYSTEM
2ND Device for Controllably affecting the Casimir force
532
534

FIG. 5

FIG. 6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518a
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I

FIG. 7

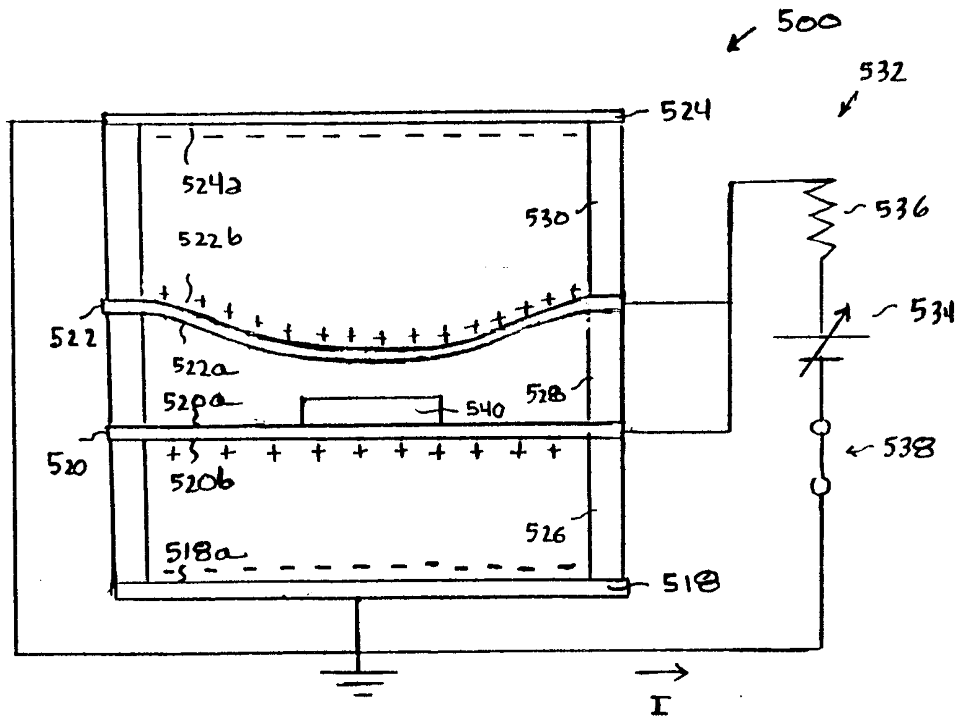
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FIG. 8

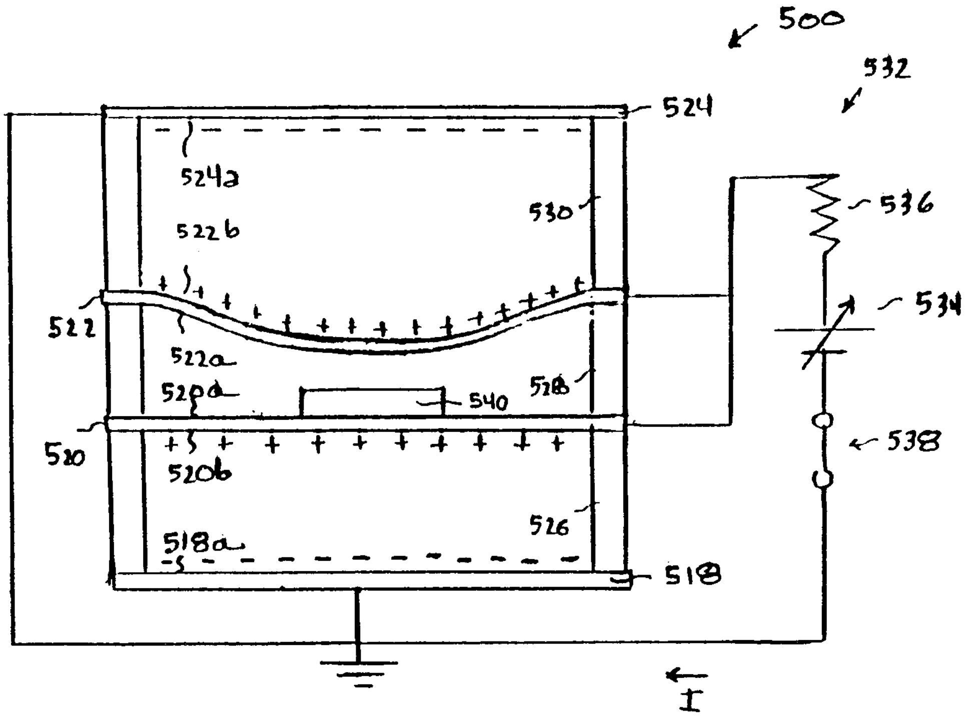
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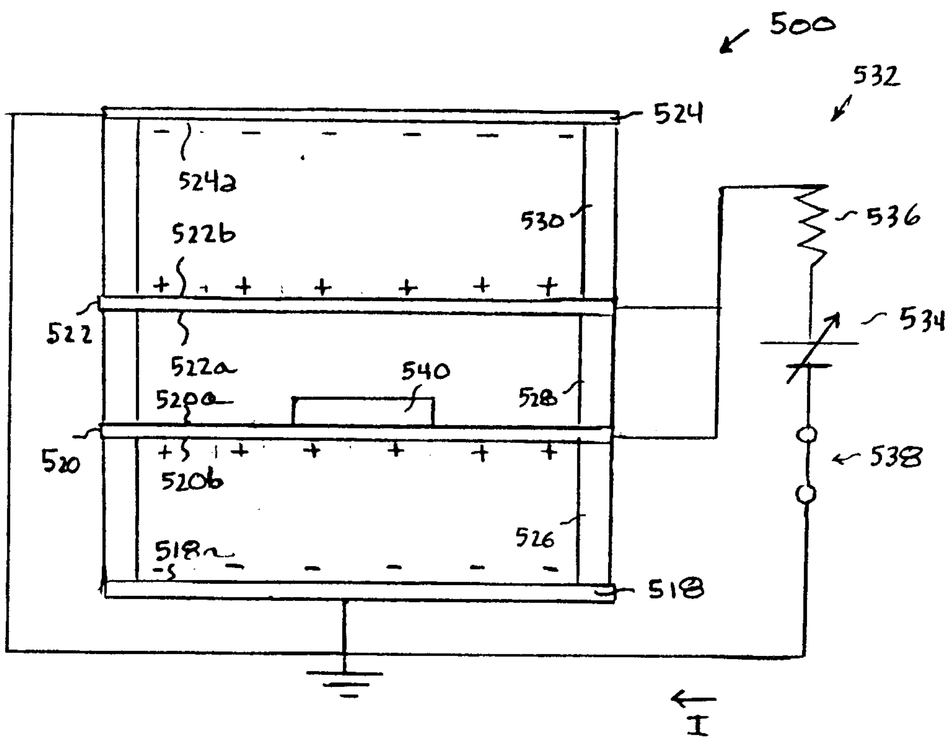
FIG. 9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524a
522b
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522a
540
520a
528
520
520b
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518a
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518
I

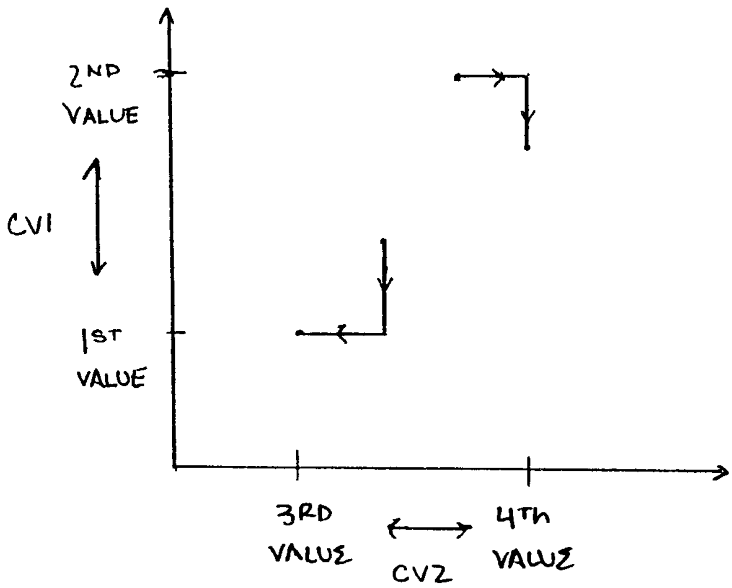


FIG. 11e

FIG. 10

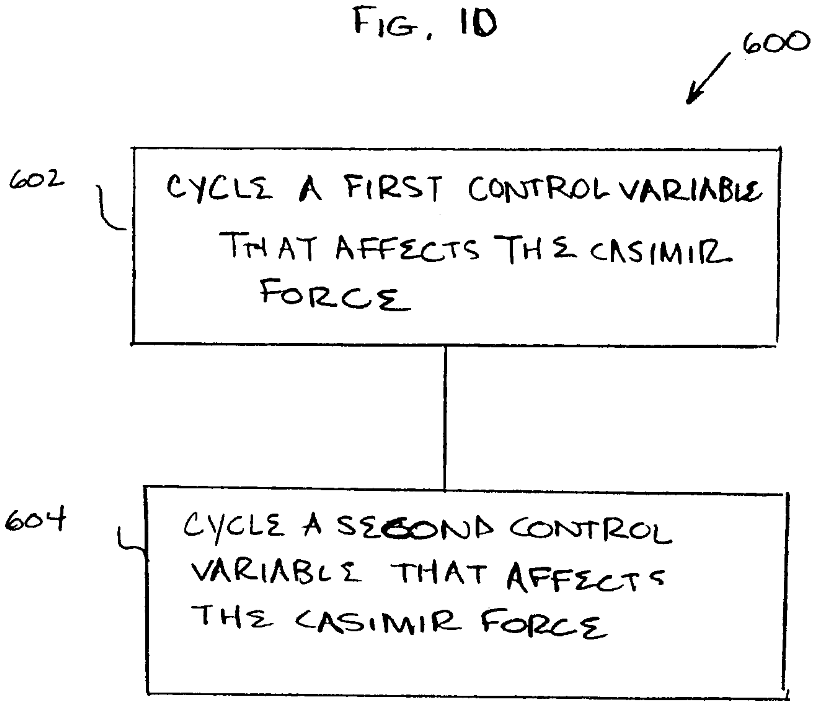


FIG. 11a

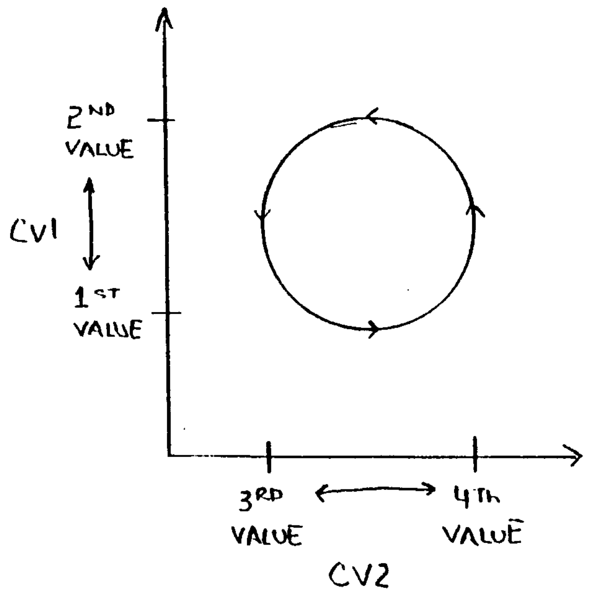
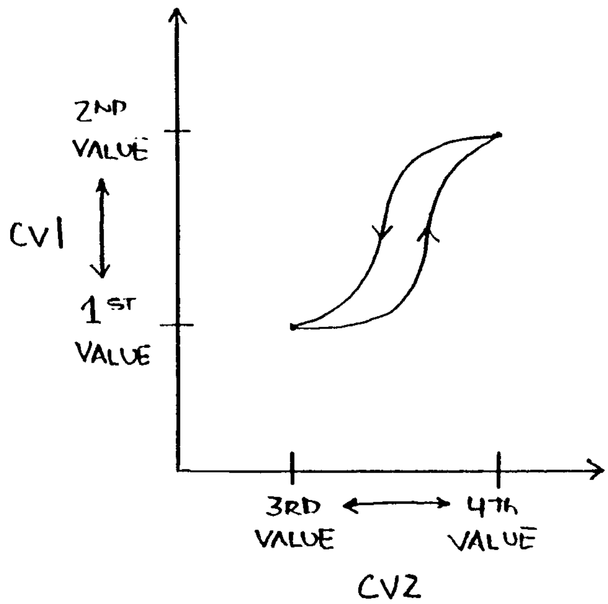


FIG. 11b



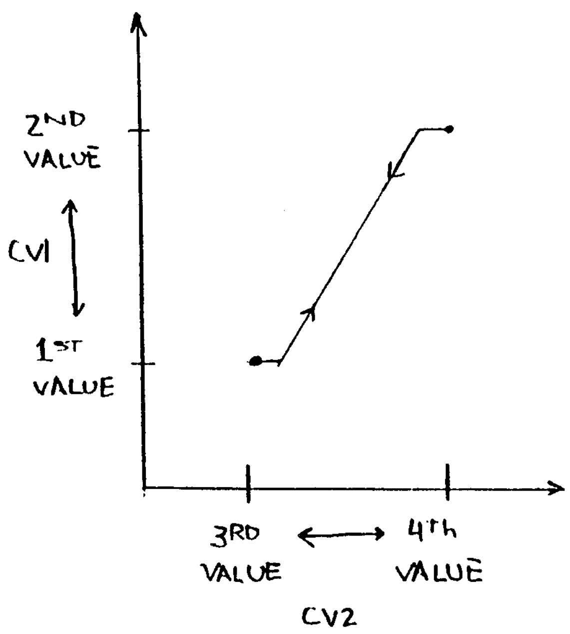


FIG. 11c

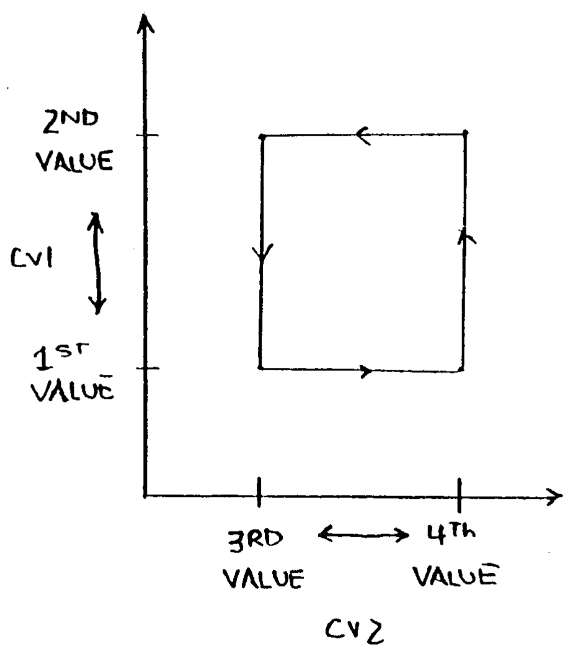


FIG 11d

FIG. 12

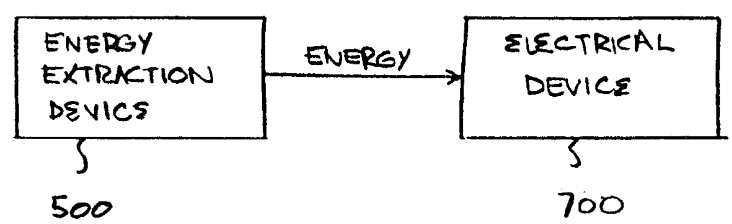
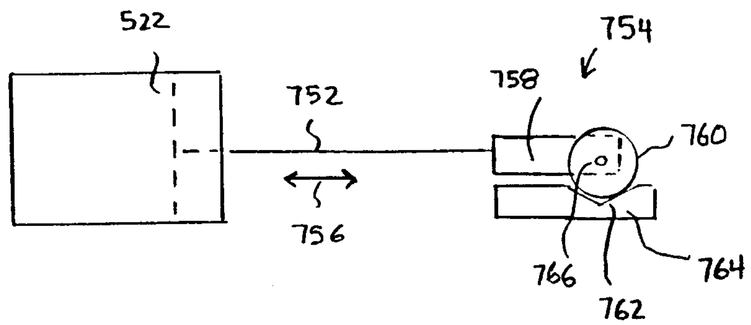

ENERGY EXTRACTION DEVICE
ENERGY
ELECTRICAL DEVICE
500
700

FIG. 13


522
752
756
754
758
760
766
762
764

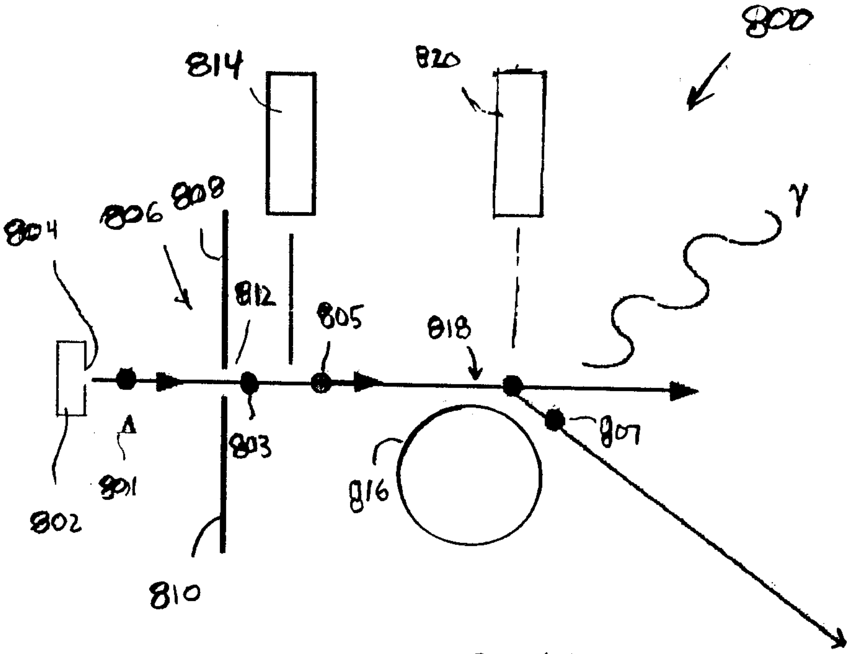

800
814
820
804
806
808
812
805
818
γ
801
802
803
810
816
807

FIG. 14

FIG. 15

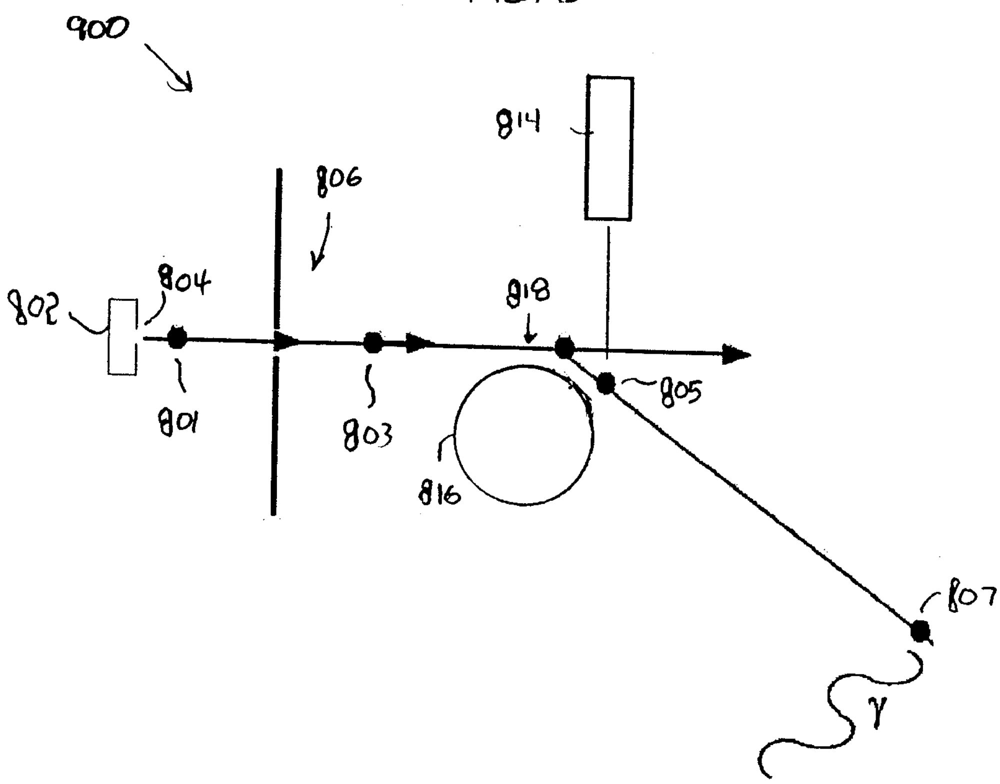

900
814
806
802
804
818
801
803
816
805
807
γ

FIG. 16

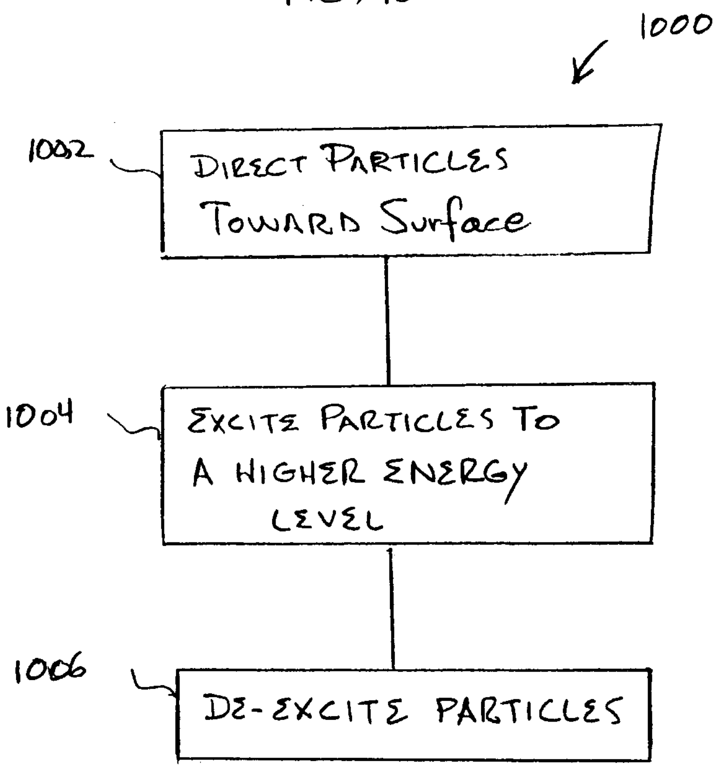

1000
1002
DIRECT PARTICLES TOWARD Surface
1004
EXCITE PARTICLES TO A HIGHER ENERGY LEVEL
1006
DE-EXCITE PARTICLES

FIG. 17

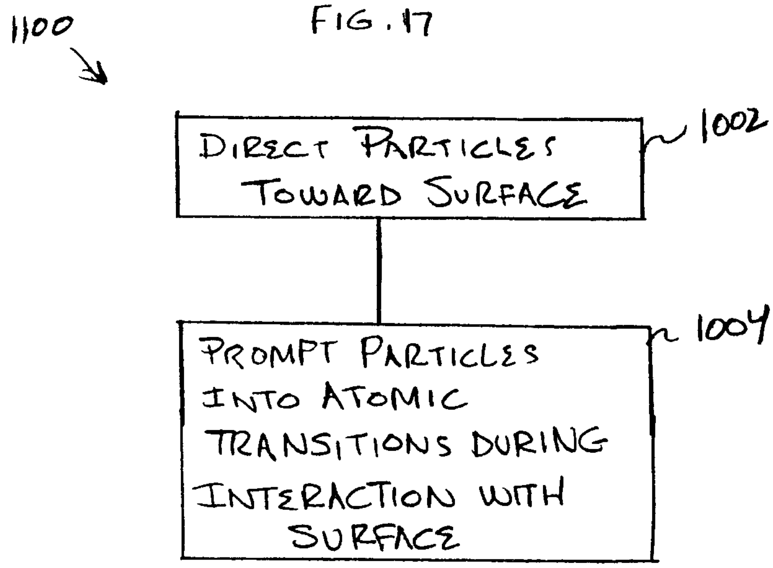
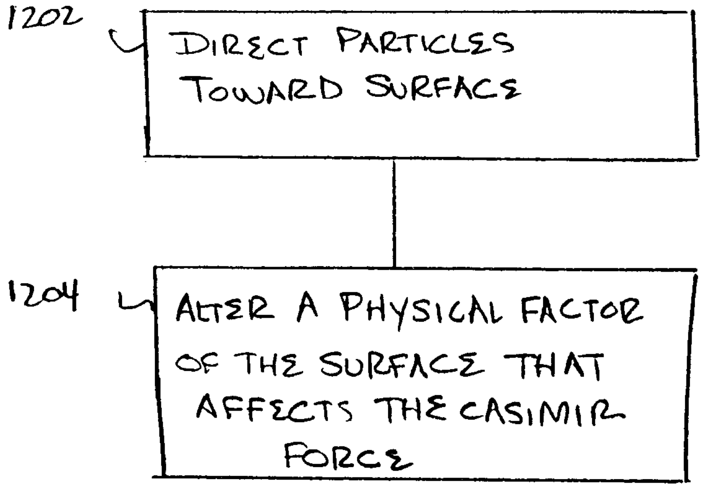

1100
DIRECT PARTICLES TOWARD SURFACE
1002
PROMPT PARTICLES INTO ATOMIC TRANSITIONS DURING INTERACTION WITH SURFACE
1004

FIG. 18


1202
DIRECT PARTICLES TOWARD SURFACE
1204
ALTER A PHYSICAL FACTOR OF THE SURFACE THAT AFFECTS THE CASIMIR FORCE

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/14672

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) :F03G 7/00; H02N 11/00
US CL :310/300
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)
U.S. : 310/300, 301; 307/151; 361/233

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
USPTO APS BRS(EAST), JPO, DERWENT

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 3541084 A1 (SPRENZEL) 06 August 1987 (06.08.1987), see entire document.	1-84
A	GB 2283611 A (LAURIE) 10 May 1995 (10.05.1995), see entire document.	1-84
A	GB 2325778 A (HUGHES et al.) 02 December 1998 (02.12.1998), see entire document.	1-84
A	US 5,590,031 A (MEAD, JR. et al.) 31 December 1996 (31.12.1996), see entire document.	1-84
A	US 5,861,701 A (YOUNG et al.) 19 January 1999 (19.01.1999), see entire document.	1-84

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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

Date of the actual completion of the international search	Date of mailing of the international search report
28 JULY 2000	30 AUG 2000

Name and mailing address of the ISA/US	Authorized officer
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Form PCT/ISA/210 (second sheet) (July 1998)★