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(71) Applicant (for all designated States except US): **REMON MEDICAL TECHNOLOGIES LTD.** [IL/IL]; Industrial Park, 7 Halamish Street, 38 900 Caesarea (IL).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **DORON, Eyal** [IL/IL]; 19 Marganit Street, 29 500 Kiryat Yam (IL). **PENNER, Avraham** [IL/IL]; 1 Boyer Street, 69 127 Tel Aviv (IL).

(74) Agent: **G. E. EHRLICH (1995) LTD.**; 28 Bezalel Street, 52 521 Ramat Gan (IL).

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(54) Title: DEVICES FOR INTRABODY DELIVERY OF MOLECULES AND SYSTEMS AND METHODS UTILIZING SAME

(57) Abstract: A device for controlled release of molecules is provided. the device including: (a) a device body having at least one reservoir therein for containing the molecules, the at least one reservoir being formed with a barrier impermeable to the molecules thereby preventing release thereof from the at least one reservoir; and (b) at least one acoustic transducer being attached to, or forming a part of, the device body, the at least one acoustic transducer being for converting an acoustic signal received thereby into an electrical signal, the electrical signal leading to barrier permeabilization and therefore release of the molecules from the at least one reservoir.



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DEVICES FOR INTRABODY DELIVERY OF MOLECULES AND SYSTEMS AND METHODS UTILIZING SAME

FIELD AND BACKGROUND OF THE INVENTION

5 The present invention relates to a device for intrabody delivery of molecules, to a method and system of utilizing same and to a method of fabricating same. More particularly, embodiments of the present invention relate to a drug delivery device which utilizes an acoustic transducer for generating an electrical activation signal from an acoustic signal received
10 thereby.

 The efficacy of drug treatment is oftentimes dependent upon the mode of drug delivery.

 Localized drug delivery is oftentimes preferred since it traverses limitations associated with systemic drug delivery including rapid drug
15 inactivation and/or ineffectual drug concentrations at the site of treatment. In addition, in some cases, systemic drug delivery can lead to undesired cytotoxic effects at tissue regions other than that to be treated.

 Since localized intrabody delivery of medication is central to efficient medical treatment attempts have been made to design and fabricate intrabody
20 delivery devices which are capable of controlled and localized release of a wide variety of molecules including, but not limited to, drugs and other therapeutics.

 Controlled release polymeric devices have been designed to provide drug release over a period of time via diffusion of the drug out of the polymer
25 and/or degradation of the polymer over the desired time period following administration to the patient. Although these devices enable localized drug delivery, their relatively simple design is limited in that it does not enable accurate and controlled delivery of the drug.

 U.S. Pat. No. 5,490,962 to Cima, et al. discloses the use of three
30 dimensional printing methods to make more complex devices which provide release over a desired time frame, of one or more drugs. Although the general

procedure for making a complex device is described, specific designs are not detailed.

U.S. Pat. No. 4,003,379 to Ellinwood describes an implantable electromechanically driven device that includes a flexible retractable walled container, which receives medication from a storage area via an inlet and then dispenses the medication into the body via an outlet.

U.S. Pat. Nos. 4,146,029 and 3,692,027 to Ellinwood disclose self-powered medication systems that have programmable miniaturized dispensing means.

U.S. Pat. No. 4,360,019 to Jassawalla discloses an implantable infusion device that includes an actuating means for delivery of the drug through a catheter. The actuating means includes a solenoid driven miniature pump.

Since such devices include miniature power-driven mechanical parts which are required to operate in the body, i.e., they must retract, dispense, or pump, they are complicated and subject to frequent breakdowns. Moreover, due to complexity and size restrictions, they are unsuitable for delivery of more than a few drugs or drug mixtures at a time.

U.S. Pat. Nos. 6,123,861 and 5,797,898 both to Santini, Jr., et al. disclose microchips devices which control both the rate and time of release of multiple chemical substances either in a continuous or a pulsatile manner. Such microchip devices employ a reservoir cap which is fabricated of a material that either degrades or allows the molecules to diffuse passively out of the reservoir over time or materials that oxidize and dissolve upon application of an electric potential. Release from the microchip device can be controlled by a preprogrammed microprocessor, via a radiofrequency (RF) activation signal, or by biosensors.

Although the microchip device described by Santini, Jr., et al. presents substantial improvements over other prior art devices, it suffers from several inherent limitations which will be described in detail hereinbelow.

There is thus a widely recognized need for, and it would be highly advantageous to have, a delivery device and methods of fabricating and utilizing same which device can be used for accurate and timely delivery of a drug or drugs within a body tissue region devoid of the above limitation.

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SUMMARY OF THE INVENTION

According to one aspect of the present invention there is provided a device for controlled release of molecules comprising: (a) a device body having at least one reservoir therein for containing the molecules, the at least one reservoir being formed with a barrier impermeable to the molecules thereby preventing release thereof from the at least one reservoir; and (b) at least one acoustic transducer being attached to, or forming a part of, the device body, the at least one acoustic transducer being for converting an acoustic signal received thereby into an electrical signal, the electrical signal leading to barrier permeabilization and therefore release of the molecules from the at least one reservoir.

According to an additional aspect of the present invention there is provided system for localized delivery of molecules within the body comprising: (a) an intrabody implantable device including: (i) a device body having at least one reservoir therein for containing the molecules, the at least one reservoir being formed with a barrier impermeable to the molecules thereby preventing release thereof from the at least one reservoir; and (ii) at least one acoustic transducer being attached to, or forming a part of, the device body, the at least one acoustic transducer being for converting an acoustic signal received thereby into an electrical signal, the electrical signal leading to barrier permeabilization and therefore release of the molecules from the at least one reservoir; and (b) an extracorporeal unit for generating the acoustic signal.

According to another aspect of the present invention there is provided a method of delivering molecules to a specific body region, the method

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comprising: (a) implanting within the body region a device including: (i) a device body having at least one reservoir therein containing the molecules, the at least one reservoir being formed with a barrier impermeable to the molecules thereby preventing release thereof from the at least one reservoir; and (ii) at least one acoustic transducer being attached to, or forming a part of, the device body, the at least one acoustic transducer being for converting an acoustic signal received thereby into an electrical signal, the electrical signal leading to barrier permeabilization and therefore release of the molecules from the at least one reservoir; and (b) extracorporeally irradiating the body with an acoustic signal thereby causing the subsequent release of the molecules from the at least one reservoir.

According to further features in preferred embodiments of the invention described below, the device further comprising a cathode, and an anode, whereas the electrical signal generates an electric potential between the cathode and the anode leading to permeabilization of the barrier and release of the molecules from the at least one reservoir.

According to still further features in the described preferred embodiments the anode is attached to or forms at least a part of the barrier.

According to still further features in the described preferred embodiments the electrical signal directly generates the electric potential between the cathode and the anode.

According to still further features in the described preferred embodiments the device further comprising a power source for generating the electric potential between the cathode and the anode upon receiving the electrical signal from the at least one acoustic transducer.

According to still further features in the described preferred embodiments the at least one acoustic transducer serves as an acoustic switch.

According to still further features in the described preferred embodiments permeabilization of the barrier is effected by at least partial disintegration thereof.

According to still further features in the described preferred embodiments a type or duration of the electrical signal controls a degree of permeabilization of the barrier and thus an amount of the molecules released.

According to still further features in the described preferred
5 embodiments the device includes a plurality of reservoirs.

According to still further features in the described preferred embodiments the device includes a plurality of acoustic transducers.

According to still further features in the described preferred
10 embodiments each of the plurality of acoustic transducers generates an electrical signal which leads to permeabilization of a barrier of a corresponding reservoir of the plurality of reservoirs.

According to still further features in the described preferred
15 embodiments each of the plurality of acoustic transducers is capable of converting an acoustic signal of a distinct frequency or frequencies into the electrical signal.

According to still further features in the described preferred
embodiments the plurality of reservoirs are for containing different types of molecules, different amounts of molecules, or combinations thereof.

According to still further features in the described preferred
20 embodiments the molecules are drug molecules.

According to still further features in the described preferred
embodiments the at least one acoustic transducer includes: (i) a cell member having a cavity; (ii) a substantially flexible piezoelectric layer attached to the cell member, the piezoelectric layer having an external surface and an internal
25 surface, the piezoelectric layer featuring such dimensions so as to enable fluctuations thereof at its resonance frequency upon impinging of an external acoustic wave; and (iii) a first electrode attached to the external surface and a second electrode attached to the internal surface.

According to still further features in the described preferred
30 embodiments the device includes a plurality of reservoirs each containing

molecules of a specific type and each capable of releasing the molecules upon provision of an acoustic signal of a specific frequency or frequencies, such that a frequency content of the acoustic signal determines a type of the molecules released.

5 According to an additional aspect of the present invention there is provided a device for controlled drug release comprising: (a) a device body including at least one reservoir being for containing a prodrug form of a drug, the at least one reservoir being formed with a barrier impermeable to the prodrug thereby preventing release thereof from the at least one reservoir; and
10 (b) at least one acoustic transducer being attached to, or forming a part of the device body, the at least one acoustic transducer being for converting an acoustic signal received thereby into an electrical signal, the electrical signal leading to a conversion of the prodrug into the drug, the drug being capable of traversing the barrier thereby releasing from the at least one reservoir.

15 According to yet an additional aspect of the present invention there is provided a system for localized delivery of molecules within the body comprising: (a) an intrabody implantable device including: (i) a device body including at least one reservoir being for containing a prodrug form of a drug, the at least one reservoir being formed with a barrier impermeable to the
20 prodrug thereby preventing release thereof from the at least one reservoir; and (ii) at least one acoustic transducer being attached to, or forming a part of the device body, the at least one acoustic transducer being for converting an acoustic signal received thereby into an electrical signal, the electrical signal leading to a conversion of the prodrug into the drug, the drug being capable of
25 traversing the barrier thereby releasing from the at least one reservoir; and (b) an extracorporeal unit for generating the acoustic signal.

According to still further features in the described preferred embodiments a type or duration of the electrical signal controls a degree of the conversion and thus an amount of the drug formed and released

According to still further features in the described preferred
embodiments the device includes a plurality of reservoirs and a plurality of
acoustic transducers, each of the plurality of acoustic transducers generates an
electrical signal which leads to the conversion of the prodrug to the drug
5 contained in a corresponding reservoir of the plurality of reservoirs.

According to still further features in the described preferred
embodiments the plurality of reservoirs are for containing different types of
prodrugs, different amounts of prodrugs, or combinations thereof.

According to still an additional aspect of the present invention there is
10 provided a method of fabricating a device for controllable release of
molecules, the method comprising: (a) providing a substrate; (b) configuring
the substrate with at least one reservoir; (c) capping the at least one reservoir
with a cap material which acts as an impermeable barrier to the molecules, the
material becoming permeable to the molecules following generation of an
15 electrical potential in or around the at least one reservoir; and (d) providing an
inlet port for filling the at least on reservoir with the molecules, the inlet being
sealable following the filling, thereby generating the device for controllable
release of molecules.

According to still further features in the described preferred
20 embodiments the method further comprising the step of: (e) attaching to, or
fabricating within, the substrate, at least one acoustic transducer, the at least
one acoustic transducer being for generating an electrical signal from an
acoustic signal received thereby, the electrical signal leading to generation of
the electrical potential in or around the at least one reservoir.

25 According to still further features in the described preferred
embodiments the at least one acoustic transducer includes: (i) a cell member
having a cavity; (ii) a substantially flexible piezoelectric layer attached to the
cell member, the piezoelectric layer having an external surface and an internal
surface, the piezoelectric layer featuring such dimensions so as to enable
30 fluctuations thereof at its resonance frequency upon impinging of an external

acoustic wave; and (iii) a first electrode attached to the external surface and a second electrode attached to the internal surface.

According to still further features in the described preferred embodiments step (b) is effected by etching the substrate.

5 The present invention successfully addresses the shortcomings of the presently known configurations by providing a device, system and method for efficient intrabody delivery of molecules such as drugs as well as a method of manufacture.

10 BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings. With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred
15 embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the
20 description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

In the drawings:

FIG. 1 is a cross sectional view of a general configuration of the device of the present invention;

25 FIGS. 2-3 illustrate cross sectional views of a prior art transducer element utilizable by the device of the present invention;

FIG. 4 illustrates a "direct activation" configuration of the device of the present invention;

FIG. 5 illustrates an "indirect activation" configuration of the device of
30 the present invention;

FIG. 6 is a schematic diagram illustrating an acoustic switch utilizable by the device of the present invention;

FIG. 7 is a black box diagram of a drug delivery system according to the teachings of the present invention; and

5 FIG 8 is schematic diagram illustrating a control circuitry of the acoustic switch illustrated in Figure 6.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is of a device, system and method which can be
10 used for localized intrabody delivery of molecules. Specifically, the present invention can be used to release molecules such as drugs within a specific body region using an acoustic activation signal provided from outside the body.

The principles and operation of the present invention may be better
15 understood with reference to the drawings and accompanying descriptions.

Before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is capable
20 of other embodiments or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

Referring now to the drawings, Figure 1 illustrates the device for controlled release of molecules, which is referred to herein as device **10**.

25 Device **10** includes a device body **12** having at least one reservoir **14** formed therein for containing the molecules to be delivered.

Preferably, device body **12** includes a plurality of reservoirs **14** (four shown in Figure 1) each being configured for containing therapeutic molecules such as drugs and/or diagnostic molecules such as dyes preferably in a solution

or as a suspension. Reservoirs **14** can be of various dimensions depending on the molecule type and quantity to be delivered therefrom.

Device body **12** can be of a planar shape, spheroidal shape or any shape suitable for intrabody implantation and delivery of molecules stored thereby.

5 Reservoirs **14** can be formed within a surface of device body **12** or within an interior volume thereof, provided molecules released therefrom can disperse into a medium surrounding device **10**.

The dimensions of device **10** are limited by the site of implantation and delivery, the quantity of drugs or drugs to be delivered thereby, and the
10 specific components used thereby for drug release activation.

Reservoirs **14** can be formed within device body **12** using any method known in the art including, but not limited to, etching, machining and the like. Alternatively, device body **12** may be pre-formed with reservoirs **14** by, for example, casting or milling techniques.

15 Device body **12** is fabricated from a material which is impermeable to the molecules to be delivered and to the surrounding fluids, for example, water, blood, electrolytes or other solutions. Examples of suitable materials include ceramics, semiconductors, biological membranes, and degradable and non-degradable polymers; biocompatibility is preferred, but not required.

20 For *in-vivo* applications, non-biocompatible materials may be encapsulated in a biocompatible material, such as polyethyleneglycol or polytetrafluoroethylene-like materials, before use. One example of a strong, non-degradable, easily etched substrate that is impermeable to the molecules to be delivered and the surrounding fluids is silicon.

25 Alternatively, device body **12** can also be fabricated from a material which degrades or dissolves over a period of time into biocompatible components such as Polyvinyl Alcohol (PVA). This embodiment is preferred for in vivo applications where the device is implanted and physical removal of the device at a later time is not feasible or recommended, as is the case with,
30 for example, brain implants. An example of a class of strong, biocompatible

materials are the poly(anhydride-co-imides) discussed by K. E. Uhrich et al., "Synthesis and characterization of degradable poly(anhydride-co-imides)", *Macromolecules*, 1995, 28, 2184-93.

Reservoir **14** is formed (capped) with a barrier **16** which is impermeable
5 to the molecules to be delivered. As such barrier **16** serves for preventing molecules contained within reservoir **14** from releasing into the surrounding medium when device **10** is implanted within the body.

Reservoir **14** can be filled with molecules of interest either prior to capping with barrier **16** or following such capping. In the latter case, reservoir
10 **14** also includes an inlet port **18**, which serves for filling reservoir **14** with molecules of choice following fabrication of device **10**. Inlet port **18** is designed to be sealable following filling, such that accidental drug release therefrom does not occur.

Device **10** further includes at least one acoustic transducer **20**. Acoustic
15 transducer **20** can be attached to, or it can form a part of, device body **12**. Acoustic transducer **20** serves for converting an acoustic signal received thereby into an electrical signal. The electrical signal generated by transducer **20** is preferably rectified via a full or half-bridge rectifier into a DC current signal. The converted electrical signal can be used to directly or indirectly
20 release the molecules stored in reservoir **14** as described hereinbelow.

According to a preferred embodiment of the present invention, the electrical signal generates (directly or indirectly) an electrical potential within reservoir **14**.

To this end, device **10** further includes at least one pair of electrodes **21**,
25 which are preferably positioned within reservoir **14** and which serve for providing the electrical potential therein.

According to one preferred embodiment of the present invention, the electrical potential converts the molecules stored within reservoir **14** into an active and barrier permeable form.

For example, the molecules contained within reservoir **14** can be provided as large aggregates which are unable to traverse barrier **16** which can be, in this case, a size selective membrane. Upon provision of the electrical potential the molecules disaggregate into smaller active units which are able to
5 diffuse out of reservoir **14** through barrier **16**.

According to another preferred embodiment of the present invention, the electrical potential leads to permeabilization of barrier **16** and subsequent release of the molecules from reservoir **14**.

For example, the electrical potential generated by electrodes **21** can
10 cause the partial or full disintegration of barrier **16** and as such the release of the molecules from reservoir **14**.

In such a case, barrier **16** can be composed of a thin film of conductive material that is deposited over the reservoir, patterned to a desired geometry, and function as an anode **22**. The size and placement of cathode **23** depends
15 upon the device's application and method of electric potential control.

Conductive materials capable of dissolving into solution or forming soluble compounds or ions upon the application of an electric potential, include, but are not limited to, metals such as copper, gold, silver, and zinc and some polymers.

20 Thus, according to this configuration of device **10**, when an electric potential is applied between anode **22** and cathode **23**, the conductive material of the anode above the reservoir oxidizes to form soluble compounds or ions that dissolve into solution, exposing the molecules to be delivered to the surrounding medium.

25 Alternatively, the application of an electric potential can be used to create changes in local pH near barrier **16** thereby leading to dissolving of barrier **16** and release of the molecules.

Still alternatively, the application of an electric potential can be used to create changes in the net charge of barrier **16** or the net charge or solubility of

the molecules thereby enabling barrier **16** traversing.

In any case, the molecules to be delivered are released into the surrounding medium by diffusion out of or by degradation or dissolution of the release system. The frequency and quantity of release can be controlled via the
5 acoustic signal received by acoustic transducer **20** as is further described hereinbelow.

According to a preferred embodiment of the present invention and as specifically shown in Figures 2-3, acoustic transducer **20** includes at least one cell member **22** including a cavity **24** etched or drilled into a substrate and
10 covered by a substantially flexible piezoelectric layer **26**. Attached to piezoelectric layer **26** are an upper electrode **28** and a lower electrode **30** which are connectable to an electronic circuit.

The substrate is preferably made of an electrical conducting layer **32** disposed on an electrically insulating layer **34**, such that cavity **24** is etched substantially
15 through the thickness of electrically conducting layer **32**.

Electrically conducting layer **32** is preferably made of copper and insulating layer **34** is preferably made of a polymer such as polyimide. Conventional copper-plated polymer laminate such as KaptonTM sheets may be used for the production of transducer **20**. Commercially available laminates such as
20 NovacladTM may be used. Alternatively, the substrate may include a silicon layer, or any other suitable material. Alternatively, layer **32** is made of a non-conductive material such as PyralinTM.

An insulating chamber **36** is etched into the substrate, preferably through the thickness of conducting layer **32**, so as to insulate the transducer
25 element from other portions of the substrate which may include other electrical components such as other transducer elements etched into the substrate.

According to a specific embodiment, the width of insulating chamber **36** is about 100 μm . As shown, insulating chamber **36** is etched into the substrate so as to form a wall **38** of a predetermined thickness enclosing cavity

24, and a conducting line 40 integrally made with wall 38 for connecting the transducer element to another electronic component preferably etched into the same substrate, or to an external electronic circuit.

Upper electrode 28 and lower electrode 30 are preferably precisely
5 shaped, so as to cover a predetermined area of piezoelectric layer 26. Electrodes 28 and 30 may be deposited on the upper and lower surfaces of piezoelectric layer 26, respectively, by using various methods such as vacuum deposition, mask etching, painting, and the like.

Lower electrode 30 is preferably made as an integral part of a
10 substantially thin electrically conducting layer 42 disposed on electrically conducting layer 32. Preferably, electrically conducting layer 42 is made of a Nickel-Copper alloy and is attached to electrically conducting layer 32 by means of a sealing connection 44. Sealing connection 44 may be made of chemical or physical metal vapour deposition (CVD or PVD) indium.
15 According to a preferred configuration, sealing connection 44 may feature a thickness of about 10 μm , such that the overall height of wall 38 of cavity 24 is about 20-25 μm .

Preferably, cavity 24 is etched or drilled into the substrate by using conventional printed-circuit photolithography methods. Alternatively, cavity
20 24 may be etched into the substrate by using VLSI/micro-machining technology or any other suitable technology. Cavity 24 preferably includes a gas such as air. The pressure of gas within cavity 24 may be specifically selected so as to predetermine the sensitivity and ruggedness of the transducer as well as the resonant frequency of layer 26.

25 Piezoelectric layer 26 may be made of PVDF or a copolymer thereof. Alternatively, piezoelectric layer 26 is made of a substantially flexible piezoceramic. Preferably, piezoelectric layer 26 is a poled PVDF sheet having a thickness of about 9-28 μm .

Preferably, the thickness and radius of flexible layer **26**, as well as the pressure within cavity **24**, are specifically selected so as to provide a predetermined resonant frequency.

The use of a substantially flexible piezoelectric layer **26**, allows to
5 produce a miniature transducer element whose resonant frequency is such that the acoustic wavelength is much larger than the extent of the transducer. This enables the transducer to be omnidirectional even at resonance, and further allows the use of relatively low frequency acoustic signals which do not suffer from significant attenuation in the surrounding medium.

10 The configuration and acoustic properties of such an acoustic transducer and variants thereof as well as general acoustic transduction principles are described in detail in U.S. Pat. Application No. 09/000,553 and PCT Publication No. WO 99/34,453 the disclosures of which are expressly incorporated by reference as if fully set forth herein.

15 As mentioned hereinabove, the electrical signal generated by acoustic transducer **20** can directly or indirectly activate the release of the molecules from reservoir **20**.

In the direct embodiment of device **10** which is specifically shown in Figure 4, the electrical signal generated by acoustic transducer **20** is
20 communicated directly (via circuitry) to electrodes **21** to thereby generate the electrical potential.

It will be appreciated that in such cases, the degree of barrier permeabilization and as such the degree of drug release can be controlled by the duration and/or frequency of the acoustic signal and/or its intensity
25 received by acoustic transducer **20**.

It will further be appreciated that in cases where device **10** includes a plurality of reservoirs, several acoustic transducers can be utilized such that various activation schemes can be employed.

For example, device **10** can include a plurality of acoustic transducers
30 **20** each dedicated to a specific reservoir of reservoirs **14**. In such a case, each

acoustic transducer **20** can function within a specific frequency range and as such activate release from a specific reservoir **14** only upon reception of an acoustic signal of the specific frequency of frequency range.

Such a configuration enables selective activation of specific reservoirs enabling control over the amount and rate of molecules released as well as enabling control over the type of molecules released, in cases where specific molecules are stored within specific reservoirs.

In the indirect embodiment of device **10** which is specifically shown in Figure 5, the electrical signal generated by acoustic transducer **20** serves to activate an energy storage device **54** which in turn generates the electrical potential between electrodes **21**.

In such cases, acoustic transducer **20** preferably forms a part of an acoustic switch **50** which can be configured as described below.

As specifically shown in Figure 6, acoustic switch **50** includes an electrical circuit **52** configured for performing one or more functions or commands when activated.

Acoustic switch **50** further includes an energy storage device **54** (power source) and an acoustic transducer **20** coupled to electrical circuit **52** and energy storage device **54**.

In addition, acoustic switch **50** also includes a switch **56**, such as the switch described in the Examples section below, although alternatively other switches, such as a miniature electromechanical switch and the like (not shown) may be provided.

Energy storage device **54** may be any of a variety of known devices, such as an energy exchanger, a battery and/or a capacitor (not shown). Preferably, energy storage device **54** is capable of storing electrical energy substantially indefinitely. In addition, energy storage device **54** may be capable of being charged from an external source, e.g., inductively, as will be appreciated by those skilled in the art. In a preferred embodiment, energy

storage device 54 includes both a capacitor and a primary, non-rechargeable battery. Alternatively, energy storage device 54 may include a secondary, rechargeable battery and/or capacitor that may be energized before activation or use of acoustic switch 50.

5 Acoustic switch 50 operates in one of two modes, a “sleep” or “passive” mode when not in use, and an “active” mode, when commanding electrical energy delivery from energy storage device 54 to electrical circuit 52 in order to activate release of molecules from reservoir 14 as described hereinabove.

10 When in the sleep mode, there is substantially no energy consumption from energy storage device 54, and consequently, acoustic switch 50 may remain in the sleep mode virtually indefinitely, i.e., until activated. Thus, acoustic switch 50 may be more energy efficient and, therefore, may require a smaller capacity energy storage device 54 than power switching devices that
15 continuously draw at least a small amount of current in their “passive” mode.

To activate the acoustic switch, one or more external acoustic energy waves or signals 57 are transmitted until a signal is received by acoustic transducer 20. Upon excitation by acoustic wave(s) 57, acoustic transducer 20
20 produces an electrical output that is used to close, open, or otherwise activate switch 56. Preferably, in order to achieve reliable switching, acoustic transducer 20 is configured to generate a voltage of at least several tenths of a volt upon excitation that may be used as an activation signal to close switch 56.

As a safety measure against false positives (either erroneous activation
25 or deactivation), switch 56 may be configured to close only upon receipt of an initiation signal followed by a confirmation signal. For example, an activation signal that includes a first pulse followed by a second pulse separated by a predetermined delay may be employed.

It will be appreciated that in the case of device **10** of the present invention, the use of a confirmation signal may be particularly advantageous since it can prevent unintentional release of drugs.

In addition to an activation signal, acoustic transducer **20** may be
5 configured for generating a termination signal in response to a second acoustic excitation (which may be of different frequency or duration than the activation signal) in order to return acoustic switch **50** to its sleep mode.

For example, once activated, switch **56** may remain closed indefinitely, e.g., until energy storage device **54** is depleted or until a termination signal is
10 received by acoustic transducer **20**. Alternatively, acoustic switch **50** may include a timer (not shown), such that switch **56** remains closed only for a predetermined time, whereupon it may automatically open, returning acoustic switch **50** to its sleep mode.

Acoustic switch may also include a microprocessor unit which serves to
15 interpret the electrical signal provided from acoustic transducer **20** (e.g., frequency thereof) into a signal for switching switch **56**.

Such interpretation enables to modulate the duration and strength of an electrical potential provided within reservoir **14** by simply varying the frequency and/or duration and/or intensity modulation of the acoustic signal
20 provided from outside the body.

Additional acoustic switch configurations which are utilizable by the present invention are described in U.S. Pat. Application No. 09/690,615 filed October 16, 2000, the disclosure of which is expressly incorporated by reference as if fully set forth herein.

25 Device **10** of the present invention can form a part of a system for localized release of, for example, drugs, which is referred to herein as system **100**.

As shown in Figure 7, system **100** also includes an extracorporeal unit **102** which serves for generating an acoustic signal outside the body, which

acoustic signal is received by device **10** implanted within the body. Numerous devices capable of generating acoustic signal which can serve as extracorporeal unit **102** are known in the art, and as such no further description thereof is given herein.

5 System **100** can be used as follows. A device **10** filled with molecules is implanted within a specific body tissue. Following implantation, extracorporeal unit **102** generates an acoustic signal of a predetermined frequency and/or duration thereby activating release of the molecules from device **10** as described hereinabove.

10 Thus, the present invention provides a device, system and method useful for localized delivery of molecules such as drugs.

The device of the present invention provides several advantages over prior art devices such as those described in U.S. Pat. Nos. 6,123,861 and 5,797,898. Such advantages are afforded by the acoustic transducer
15 component of the device which functions in converting an acoustic signal into an electrical activation signal.

In sharp contrast, the device described in U.S. Pat. Nos. 6,123,861 and 5,797,898, employs radiofrequency (RF) receivers which activate drug release upon reception of an RF signal generated outside the body. The use of RF
20 activation is disadvantageous since RF signals are, at least in part, absorbed by body tissues and are directionally limited by bulky unidirectional antennas used for reception.

On the other hand, acoustic transducers, such as the one utilized by the device of the present invention, are omni-directional receivers which do not
25 require antennas and as such do not suffer from structural and functional limitations which are inherent to RF receivers.

In addition, acoustic activation requires far less energy than RF activation since acoustic waves, unlike RF waves, propagate well within the aqueous medium which forms a substantial part of body tissues.

Additional objects, advantages, and novel features of the present invention will become apparent to one ordinarily skilled in the art upon examination of the following examples, which are not intended to be limiting. Additionally, each of the various embodiments and aspects of the present invention as delineated hereinabove and as claimed in the claims section below finds experimental support in the following examples.

EXAMPLES

Acoustic switch circuitry and function

Referring again to the drawings, Figure 8, illustrates an example of circuitry and components employed by an acoustic switch **200** which is utilizable by the device of the present invention.

Switch **200** includes a piezoelectric transducer, or other acoustic transducer such the acoustic transducer described hereinabove (not shown, but connectable at locations piezo + and piezo -), a plurality of MOSFET transistors (Q1-Q4) and resistors (R1-R4), and switch S1.

In the switch's "sleep" mode, all of the MOSFET transistors (Q1-Q4) are in an off state. To maintain the off state, the gates of the transistors are biased by pull-up and pull-down resistors. The gates of N-channel transistors (Q1, Q3 & Q4) are biased to ground and the gate of P-channel transistor Q2 is biased to +3V. During this quiescent stage, switch S1 is closed and no current flows through the circuit.

Therefore, although an energy storage device (not shown, but coupled between the hot post, labeled with an exemplary voltage of +3V, and ground) is connected to the switch **200**, no current is being drawn therefrom since all of the transistors are quiescent.

When the piezoelectric transducer detects an external acoustic signal, e.g., having a particular frequency such as the transducer's resonant frequency, the voltage on the transistor Q1 will exceed the transistor threshold voltage of about one half of a volt. Transistor Q1 is thereby switched on and current

flows through transistor Q1 and pull-up resistor R2. As a result of the current flow through transistor Q1, the voltage on the drain of transistor Q1 and the gate of transistor Q2 drops from +3V substantially to zero (ground). This drop in voltage switches on the P-channel transistor Q2, which begins to conduct through transistor Q2 and pull-down resistor R3.

As a result of the current flowing through transistor Q2, the voltage on the drain of transistor Q2 and the gates of transistors Q3 and Q4 increases from substantially zero to +3V. The increase in voltage switches on transistors Q3 and Q4. As a result, transistor Q3 begins to conduct through resistor R4 and main switching transistor Q4 begins to conduct through the "load," thereby switching on the electrical circuit.

As a result of the current flowing through transistor Q3, the gate of transistor Q2 is connected to ground through transistor Q3, irrespective of whether or not transistor Q1 is conducting. At this stage, the transistors (Q2, Q3 & Q4) are latched to the conducting state, even if the piezoelectric voltage on transistor Q1 is subsequently reduced to zero and transistor Q1 ceases to conduct. Thus, main switching transistor Q4 will remain on until switch S1 is opened.

In order to deactivate or open switch 200, switch S1 must be opened, for example, while there is no acoustic excitation of the piezoelectric transducer. If this occurs, the gate of transistor Q2 increases to +3V due to pull-up resistor R2. Transistor Q2 then switches off, thereby, in turn, switching off transistors Q3 and Q4. At this stage, switch 200 returns to its sleep mode, even if switch S1 is again closed. Switch 200 will only return to its active mode upon receiving a new acoustic activation signal from the piezoelectric transducer.

It should be apparent to one of ordinary skill in the art that the above-mentioned electrical circuit is not the only possible implementation of a switch for use with the present invention. For example, the switching

operation may be performed using a CMOS circuit, which may draw less current when switched on, an electromechanical switch, and the like.

It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable subcombination.

Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims. All publications, patents and patent applications mentioned in this specification are herein incorporated in their entirety by reference into the specification, to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated herein by reference. In addition, citation or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the present invention.

WHAT IS CLAIMED IS:

1. A device for controlled release of molecules comprising:
 - (a) a device body having at least one reservoir therein for containing the molecules, said at least one reservoir being formed with a barrier impermeable to the molecules thereby preventing release thereof from said at least one reservoir; and
 - (b) at least one acoustic transducer being attached to, or forming a part of, said device body, said at least one acoustic transducer being for converting an acoustic signal received thereby into an electrical signal, said electrical signal leading to barrier permeabilization and therefore release of the molecules from said at least one reservoir.
2. The device of claim 1, further comprising a cathode, and an anode, whereas said electrical signal generates an electric potential between said cathode and said anode leading to permeabilization of said barrier and release of the molecules from said at least one reservoir.
3. The device of claim 2, wherein said anode is attached to or forms at least a part of said barrier.
4. The device of claim 2, wherein said electrical signal directly generates said electric potential between said cathode and said anode.
5. The device of claim 2, further comprising a power source for generating said electric potential between said cathode and said anode upon receiving said electrical signal from said at least one acoustic transducer.

6. The device of claim 1, wherein said at least one acoustic transducer serves as an acoustic switch.

7. The device of claim 1, wherein permeabilization of said barrier is effected by at least partial disintegration thereof.

8. The device of claim 1, wherein a type or duration of said electrical signal controls a degree of permeabilization of said barrier and thus an amount of the molecules released.

9. The device of claim 1, wherein the device includes a plurality of reservoirs.

10. The device of claim 9, wherein the device includes a plurality of acoustic transducers.

11. The device of claim 10, wherein each of said plurality of acoustic transducers generates an electrical signal which leads to permeabilization of a barrier of a corresponding reservoir of said plurality of reservoirs.

12. The device of claim 11, wherein each of said plurality of acoustic transducers is capable of converting an acoustic signal of a distinct frequency or frequencies into said electrical signal.

13. The device of claim 9, wherein said plurality of reservoirs are for containing different types of molecules, different amounts of molecules, or combinations thereof.

14. The device of claim 1, wherein the molecules are drug molecules.

15. The device of claim 1, wherein said at least one acoustic transducer includes:

- (i) a cell member having a cavity;
- (ii) a substantially flexible piezoelectric layer attached to said cell member, said piezoelectric layer having an external surface and an internal surface, said piezoelectric layer featuring such dimensions so as to enable fluctuations thereof at its resonance frequency upon impinging of an external acoustic wave; and
- (iii) a first electrode attached to said external surface and a second electrode attached to said internal surface.

16. A device for controlled drug release comprising:

- (a) a device body including at least one reservoir being for containing a prodrug form of a drug, said at least one reservoir being formed with a barrier impermeable to said prodrug thereby preventing release thereof from said at least one reservoir; and
- (b) at least one acoustic transducer being attached to, or forming a part of said device body, said at least one acoustic transducer being for converting an acoustic signal received thereby into an electrical signal, said electrical signal leading to a conversion of said prodrug into said drug, said drug being capable of traversing said barrier thereby releasing from said at least one reservoir.

17. The device of claim 16, further comprising a cathode, and an anode disposed within said at least one electrode, whereas said electrical signal generates an electric potential between said cathode and said anode leading to said conversion of said prodrug into said drug.

18. The device of claim 16, wherein said anode is attached to or forms at least a part of said barrier.

19. The device of claim 17, wherein said electrical signal directly generates said electric potential between said cathode and said anode.

20. The device of claim 17, further comprising a power source for generating said electric potential between said cathode and said anode upon receiving said electrical signal from said at least one acoustic transducer.

21. The device of claim 16, wherein said at least one acoustic transducer serves as an acoustic switch.

22. The device of claim 16, wherein a type or duration of said electrical signal controls a degree of said conversion and thus an amount of said drug formed and released

23. The device of claim 16, wherein the device includes a plurality of reservoirs.

24. The device of claim 16, wherein the device includes a plurality of acoustic transducers.

25. The device of claim 24, wherein each of said plurality of acoustic transducers generates an electrical signal which leads to said conversion of said prodrug to said drug contained in a corresponding reservoir of said plurality of reservoirs.

26. The device of claim 25, wherein each of said plurality of acoustic transducers is capable of converting an acoustic signal of a distinct frequency or frequencies into said electrical signal.

27. The device of claim 23, wherein said plurality of reservoirs are

for containing different types of prodrugs, different amounts of prodrugs, or combinations thereof.

28. The device of claim 16, wherein said at least one acoustic transducer includes:

- (i) a cell member having a cavity;
- (ii) a substantially flexible piezoelectric layer attached to said cell member, said piezoelectric layer having an external surface and an internal surface, said piezoelectric layer featuring such dimensions so as to enable fluctuations thereof at its resonance frequency upon impinging of an external acoustic wave; and
- (iii) a first electrode attached to said external surface and a second electrode attached to said internal surface.

29. A method of delivering molecules to a specific body region, the method comprising:

- (a) implanting within the body region a device including:
 - (i) a device body having at least one reservoir therein containing the molecules, said at least one reservoir being formed with a barrier impermeable to the molecules thereby preventing release thereof from said at least one reservoir; and
 - (ii) at least one acoustic transducer being attached to, or forming a part of, said device body, said at least one acoustic transducer being for converting an acoustic signal received thereby into an electrical signal, said electrical signal leading to barrier permeabilization and therefore release of the molecules from said at least one reservoir; and
- (b) extracorporeally irradiating the body with an acoustic signal thereby causing the subsequent release of the molecules from said at least one reservoir.

30. The method of claim 29, wherein said device includes a plurality of reservoirs each containing molecules of a specific type and each capable of releasing said molecules upon provision of an acoustic signal of a specific frequency or frequencies, such that a frequency content of said acoustic signal determines a type of said molecules released.

31. The method of claim 29, wherein a frequency content or duration of said acoustic signal controls a degree of permeabilization of said barrier and thus an amount of the molecules released.

32. The method of claim 29, wherein said molecules are drug molecules.

33. The method of claim 29, wherein said device further includes a cathode, and an anode, whereas said electrical signal generates an electric potential between said cathode and said anode leading to permeabilization of said barrier and release of the molecules from said at least one reservoir.

34. The method of claim 33, wherein said anode is attached to or forms at least a part of said barrier.

35. The method of claim 33, wherein said electrical signal directly generates said electric potential between said cathode and said anode.

36. The method of claim 33, wherein said device further includes a power source for generating said electric potential between said cathode and said anode upon receiving said electrical signal from said at least one acoustic transducer.

37. The method of claim 29, wherein said acoustic transducer serves as an acoustic switch.

38. A system for localized delivery of molecules within the body comprising:

- (a) an intrabody implantable device including:
 - (i) a device body having at least one reservoir therein for containing the molecules, said at least one reservoir being formed with a barrier impermeable to the molecules thereby preventing release thereof from said at least one reservoir; and
 - (ii) at least one acoustic transducer being attached to, or forming a part of, said device body, said at least one acoustic transducer being for converting an acoustic signal received thereby into an electrical signal, said electrical signal leading to barrier permeabilization and therefore release of the molecules from said at least one reservoir; and
- (b) an extracorporeal unit for generating said acoustic signal.

39. A system for localized delivery of molecules within the body comprising:

- (a) an intrabody implantable device including:
 - (i) a device body including at least one reservoir being for containing a prodrug form of a drug, said at least one reservoir being formed with a barrier impermeable to said prodrug thereby preventing release thereof from said at least one reservoir; and
 - (ii) at least one acoustic transducer being attached to, or forming a part of said device body, said at least one

acoustic transducer being for converting an acoustic signal received thereby into an electrical signal, said electrical signal leading to a conversion of said prodrug into said drug, said drug being capable of traversing said barrier thereby releasing from said at least one reservoir; and

- (b) an extracorporeal unit for generating said acoustic signal.

40. A method of fabricating a device for controllable release of molecules, the method comprising:

- (a) providing a substrate;
- (b) configuring said substrate with at least one reservoir;
- (c) capping said at least one reservoir with a cap material which acts as an impermeable barrier to the molecules, said material becoming permeable to the molecules following generation of an electrical potential in or around said at least one reservoir; and
- (d) providing an inlet port for filling said at least one reservoir with the molecules, said inlet being sealable following said filling, thereby generating the device for controllable release of molecules.

41. The method of claim 40, further comprising the step of:

- (e) attaching to, or fabricating within, said substrate, at least one acoustic transducer, said at least one acoustic transducer being for generating an electrical signal from an acoustic signal received thereby, said electrical signal leading to generation of said electrical potential in or around said at least one reservoir.

42. The method of claim 41, wherein said at least one acoustic transducer includes:

- (i) a cell member having a cavity;
- (ii) a substantially flexible piezoelectric layer attached to said cell member, said piezoelectric layer having an external surface and an internal surface, said piezoelectric layer featuring such dimensions so as to enable fluctuations thereof at its resonance frequency upon impinging of an external acoustic wave; and
- (iii) a first electrode attached to said external surface and a second electrode attached to said internal surface.

43. The method of claim 40, wherein step (b) is effected by etching said substrate.

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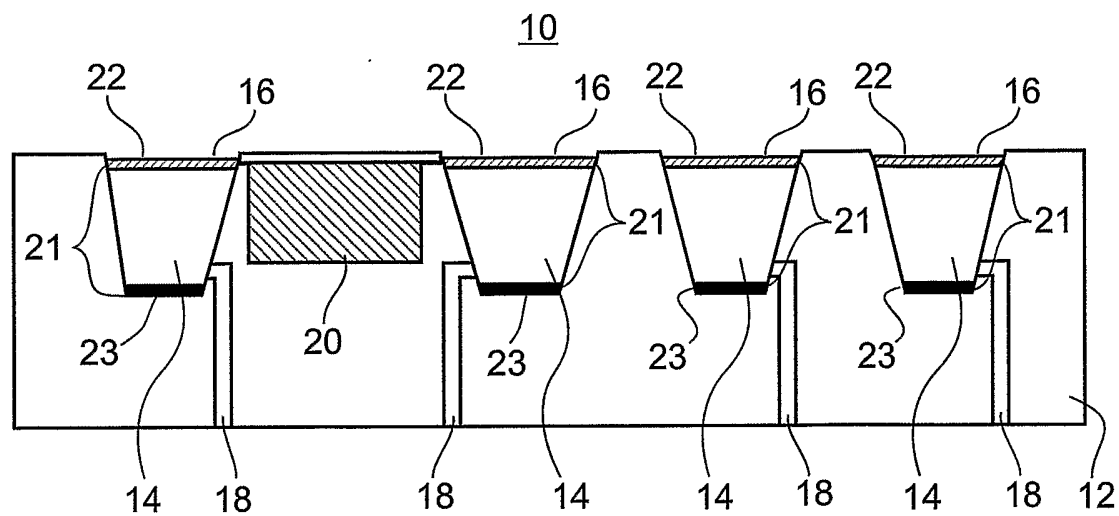


Fig. 1

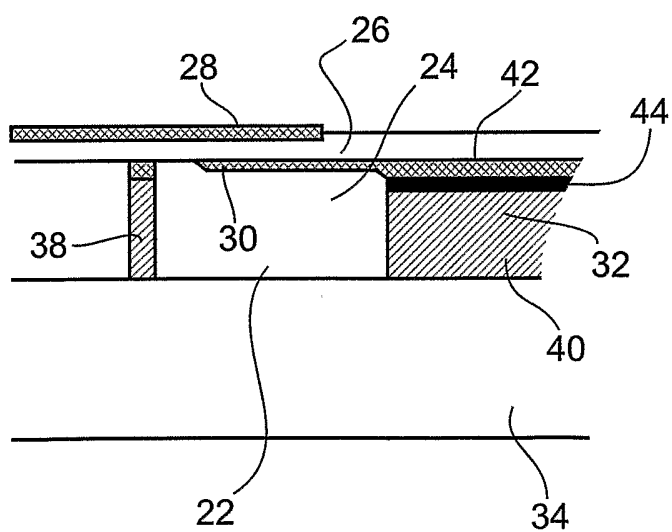


Fig. 2

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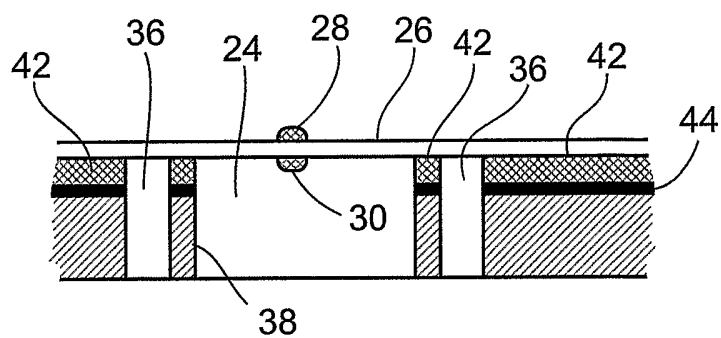


Fig. 3

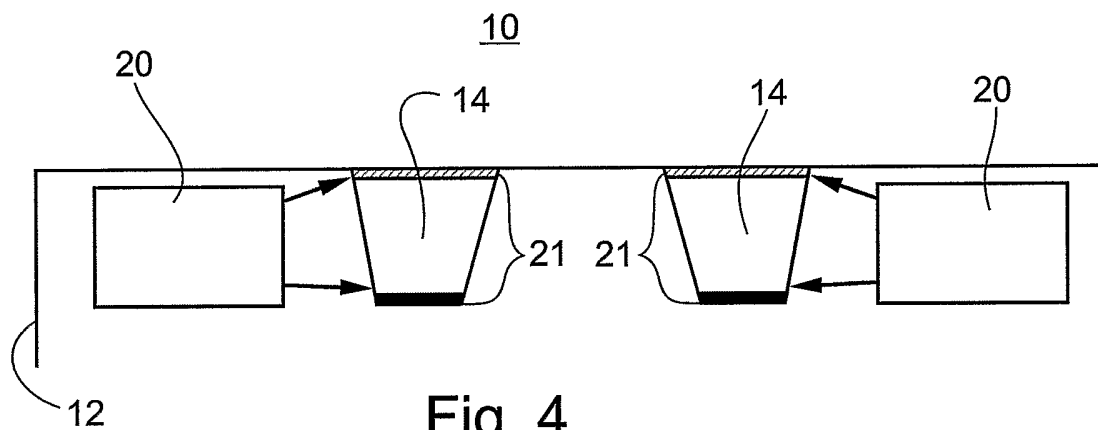


Fig. 4

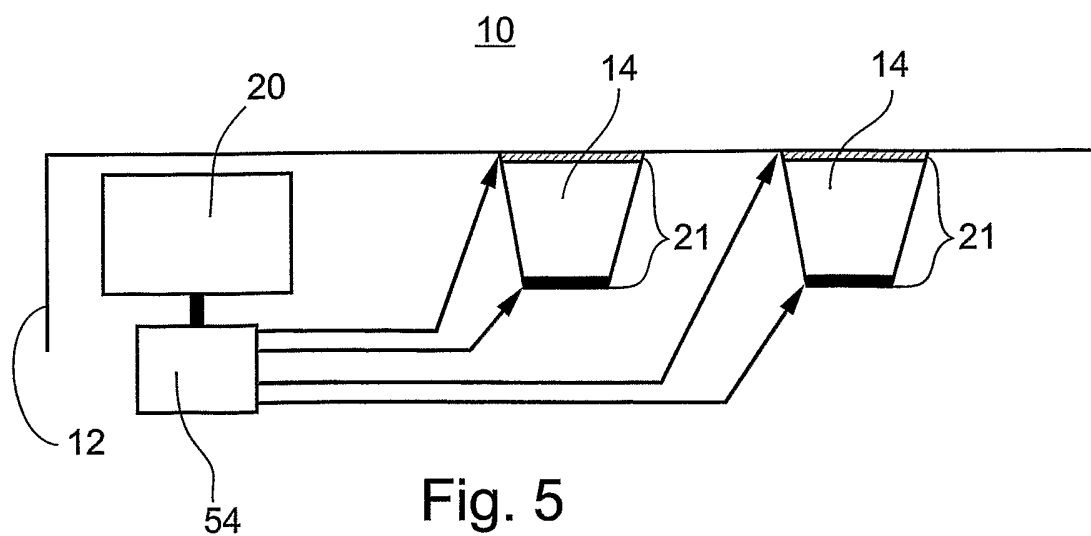


Fig. 5

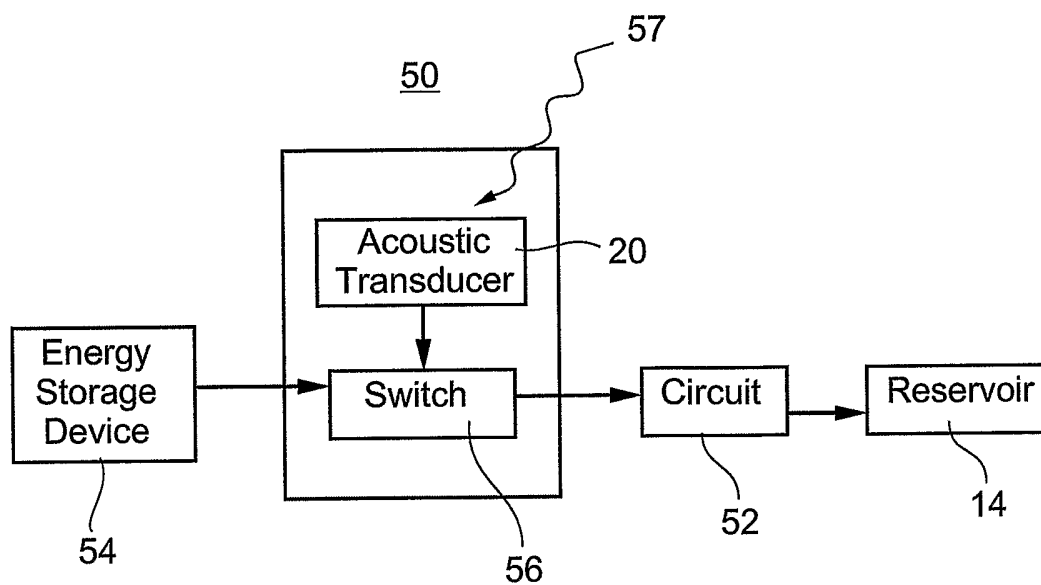


Fig. 6

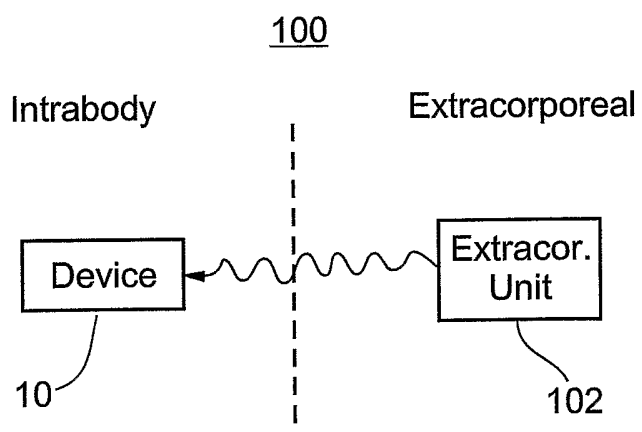


Fig. 7

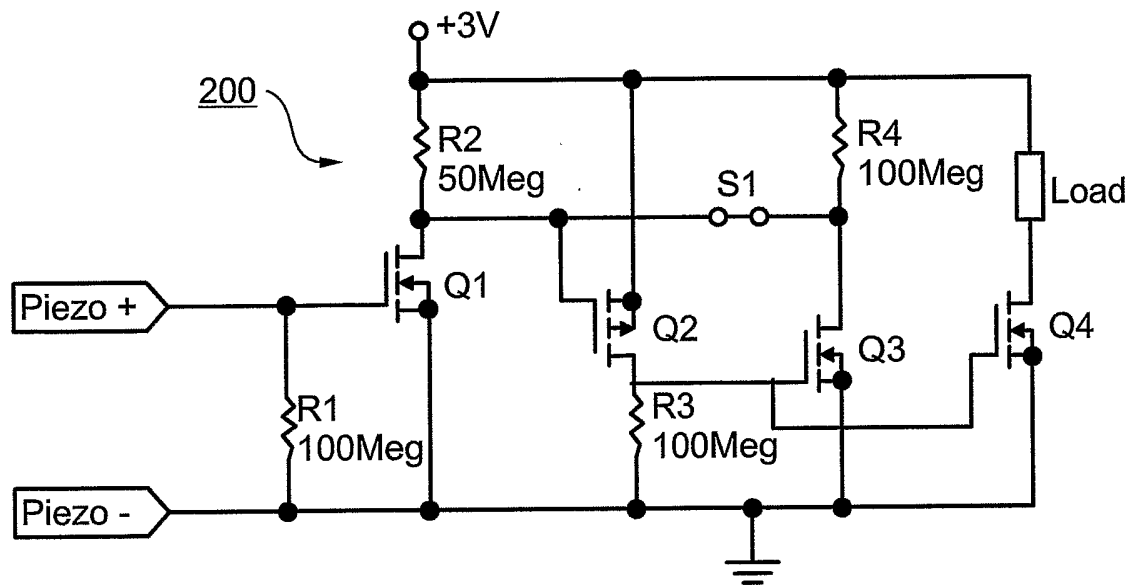


Fig. 8