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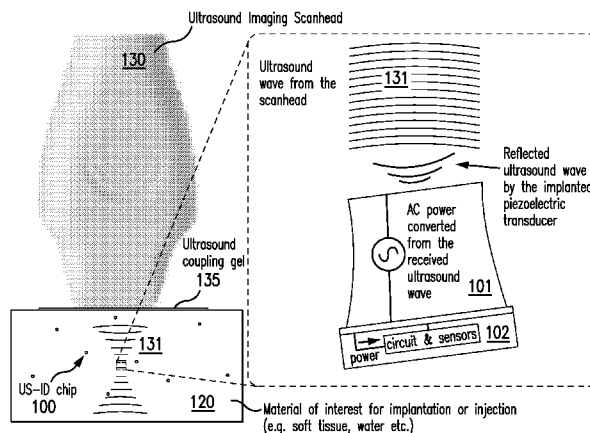


FIG. 1

(57) **Abstract:** Apparatus and methods for powering micron-scale implantable and injectable integrated circuit (IC) chips for in-vivo sensing and acquisition of various physiological signals are provided. The disclosed subject matter includes the integration of piezoelectric transducers, such as polyvinylidene fluoride (PVDF) or lead zirconate titanate (PZT), onto implantable and injectable IC chips for power transfer and data transmission using ultrasound waves generated from commercial ultrasound imaging equipment.

MICRON-SCALE ULTRASOUND IDENTIFICATION SENSING TAGS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Application Serial No. 5 62/214,822, filed on September 4, 2015, which is hereby incorporated by reference in its entirety.

BACKGROUND

Implantable and injectable electronic devices containing integrated circuit (IC) chips can aid, monitor, or support the functions of organs and even cells, and can be utilized in diagnosis and treatment of medical conditions when implanted or injected into various organs or cells. The sizes of the implantable and injectable devices can vary as a result of the inclusion of components designed to carry out the device functionalities, including the power sources. Batteries can be used as power supplies for implantable and injectable devices. However, batteries can often be bulkier than the IC chips of the implantable and injectable devices, and can require periodic replacement and recharge, limiting the applicability of those devices. Unlike the battery-based power scheme, wireless power transfer from external energy-emitting sources to the implantable and injectable devices can reduce the device size by removing the battery component.

One technique for wirelessly delivering power across biological tissues to implantable and injectable devices is that of inductive coupling. For example, inductive coupling uses a pair of antennas by which power can be transferred across biological tissues via electromagnetic (EM) waves generated from a mutual-inductively coupled link. While attractive when the distance between this pair of antennas is small, the antenna size can be larger than the sizes of the device IC chips. Additionally, certain tissue attenuation of EM waves and the drop of power transfer efficiency when the distance between antennas

increases can limit the amount of delivered power and therefore the performances of implantable or injectable devices powered by inductive coupling.

Accordingly, there is a need for improved devices and techniques for wirelessly powering implantable and injectable devices.

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SUMMARY

The presently disclosed subject matter provides devices and techniques which integrate piezoelectric transducers, such as polyvinylidene fluoride (PVDF) or lead zirconate titanate (PZT), with customized IC chips to form electronic devices that can be implanted or injected into organs/cells. These implantable and injectable devices can be wirelessly
10 powered by ultrasound waves and can wirelessly transmit data also through ultrasound, therefore referred to as ultrasound identification (USID) sensing tags. The ultrasound waves can have a frequency of 30MHz – 50MHz and can be generated from certain commercial ultrasound imaging equipment, such as, for example and without limitation, the Verasonics Vantage 256 system.

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Ultrasound can provide improved power transfer efficiency through biological tissues and enables much smaller device size due to a much smaller wavelength compared to certain other wireless power transfer techniques. For example and without limitation, the wavelength of EM waves at 40MHz are a few meters in biological tissues, while the wavelength of ultrasound at 40MHz is approximately 37.5 μ m, which is orders of magnitude
20 smaller than that of EM waves at the same frequency.

In an exemplary embodiment, the disclosed subject matter can include tens and even hundreds of micron-scale USID sensing tags implanted or injected into organs/cells of interest. Each individual tag can include a customized IC chip with a piezoelectric transducer integrated on the top surface of the chip. In some embodiments, the IC chips can
25 be formed using a conventional complementary metal-oxide-semiconductor (CMOS) process.

The CMOS process can be either a silicon-on-insulator (SOI) CMOS process or a bulk CMOS process. Each individual IC chip can be designed to have a length by width of 150 μ m by 150 μ m, and multiple IC chips can be contained in a single die. The die thickness can be approximately 300 μ m in conventional CMOS processes.

5 Die/chip thinning processes with a sequential combination of mechanical grinding followed by deep reactive-ion etching (DRIE) can be utilized to reduce the die thickness to approximately 20 μ m. The reduced die thickness not only largely decreases the overall device size of the USID sensing tags for various implantation/injection applications, but also reduces the mechanical loading effects on the piezoelectricity of the integrated
10 piezoelectric transducer. Additionally, the integrated piezoelectric transducers can have a length by width by thickness of approximately 150 μ m by 95 μ m by 28 μ m. In such a way, the USID sensing tags can have a size of approximately 150 μ m by 150 μ m by 48 μ m, therefore referred to as “micron-scale.”

 When excited emitted energy, such as from, commercial ultrasound imaging
15 equipment, an implanted or injected USID sensing tag can reflect part of the received ultrasound waves as echoes back to the equipment, which can form a brightness-mode (B-mode) ultrasound image showing the shape, location, and even movement of the tag. The level of acoustic impedance mismatch between the tag and the surrounding tissues can determine the amplitude of the returned echo signal, which then can determine the brightness
20 of the tag in the ultrasound image.

 When receiving ultrasound waves from the ultrasound imaging equipment, the herein disclosed piezoelectric transducer of a USID sensing tag can convert mechanical vibrations of ultrasound waves into electrical energy in the alternating-current (AC) form to provide power for the IC chip. Additionally, the herein disclosed IC chip of a USID sensing
25 tag can include a front-end charge pump, a relaxation oscillator, and a modulator. The charge

pump can convert the AC electrical energy generated in the integrated piezoelectric transducer into a direct-current (DC) supply to power the relaxation oscillator. The relaxation oscillator can generate a sub-10-Hz oscillation to drive the modulator.

The modulator can actively modulate the input impedance of the IC chip to
5 cause a periodic impedance change seen by the piezoelectric transducer. This periodic change in input impedance can cause a periodic change in the acoustic impedance mismatch between the tag and the surrounding tissues and therefore the reflectivity of ultrasound waves, or the amount of returned echo signal to form a B-mode image in the ultrasound imaging equipment. This can cause a periodic brightness change of the USID sensing tag in
10 the image and can indicate the powering and detection of the tag. Additional circuitry can be added and configured for sensing functionality with transduced voltages analog-to-digital-converted with a voltage-controlled oscillator, such that, for example and without limitation, changes in voltage can produce discernible changes in oscillation frequency of the backscattered ultrasound energy. Exemplary functionalities can include real-time pH
15 sensing, drug delivery and controlled release, chemical and biological activity detection, and digestion monitoring of small animals.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts the operation of multiple USID sensing tags in the organ/cell of interest in accordance with an exemplary embodiment of the disclosed subject matter.

20 **FIGS. 2A-2I** depict a fabrication process for producing the USID sensing tags in accordance with an exemplary embodiment of the disclosed subject matter.

FIG. 3 depicts a circuit block diagram in accordance with an exemplary embodiment of the disclosed subject matter.

FIG. 4 depicts a circuit schematic diagram in accordance with an exemplary
25 embodiment of the disclosed subject matter.

FIG. 5 depicts a circuit schematic diagram in accordance with an exemplary embodiment of the disclosed subject matter.

FIG. 6 depicts a circuit schematic diagram in accordance with an exemplary embodiment of the disclosed subject matter.

5 **FIG. 7** depicts a die diagram in accordance with an exemplary embodiment of
the disclosed subject matter.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and are intended to provide further explanation of the disclosed subject matter claimed.

10 The accompanying figures, where like reference numerals refer to identical or functionally similar elements throughout separate views, serve to further illustrate various embodiments and to explain various principles and advantages all in accordance with the disclosed subject matter. For purpose of explanation and illustration, and not limitation, exemplary aspects and embodiments of the device are shown in **FIGS. 1-7**.

15 **DETAILED DESCRIPTION**

The presently disclosed subject matter provides micron-scale implantable and injectable USID sensing tags, where certain IC chips are integrated with piezoelectric transducers. The USID sensing tags can be wirelessly powered and detected/imaged by ultrasound waves at 30 – 50MHz from certain commercial ultrasound imaging equipment.

20 The IC chips can be implemented in conventional CMOS processes and can be fabricated in commercial foundries. The USID sensing tags can be fabricated by integrating the piezoelectric transducers with the IC chips using a series of fabrication processes.

For the purpose of illustration and not limitation, reference is made to the exemplary USID sensing tag **100** shown in exemplary **FIG. 1**. **FIG. 1** illustrates the general operation of the presently disclosed subject matter. For example, the fabricated USID

sensing tag **100** can be implanted or injected into a material of interest **120**, such as an organ, a cell, soft tissue, or water. The scanhead **130** of commercial ultrasound imaging equipment, such as for example, the Verasonics Vantage 256 system, transmits ultrasound waves **131** to the USID sensing tag **100** through the material of interest **120**. Additionally or alternatively, and as shown in exemplary **FIG. 1**, an ultrasound coupling gel **135** can be applied in between the scanhead **130** and the surface of the material of interest **120** to improve the transmission of ultrasound waves **131** from the scanhead **130** to the USID sensing tag **100**. The ultrasound coupling gel **135** can, for example, improve transmission of ultrasound waves **131** since ultrasound waves **131** can exhibit inferior transmission through air than through the ultrasound coupling gel **135**. The mechanical energy of the ultrasound waves **131** of exemplary **FIG. 1** can be converted to electrical energy by the piezoelectric transducer **101** integrated onto the IC chip **102** of the USID sensing tag **100**. The electrical energy converted from ultrasound waves **131** can power the IC chip **102** for sensing and data transmission.

Further to the above, the disclosed subject matter can include a method for fabricating the USID sensing tags, which can include, for example and without limitation, thinning and surface planarization of the die that contains the IC chips, separation of individual IC chips on the die, passivation of the individual IC chips for biocompatibility, integration of the individual IC chips with their corresponding piezoelectric transducers, and release of the resulting devices from the die. For example, a die that contains the IC chips can be thinned from a thickness of approximately 300 μ m down to a thickness of approximately 20 μ m, which renders the originally brittle die thin and flexible. Exemplary techniques for thinning chip die can include a sequential combination of mechanical grinding followed by DRIE (deep reactive-ion etching). Other suitable thinning techniques are also within the scope of the presently disclosed subject matter.

For example and without limitation, a method of fabricating the USID sensing tags is illustrated in exemplary **FIGS. 2A-2I**. As shown in exemplary **FIG. 2A**, the thinned IC die **201** can be placed on top of a backing layer made of aluminum for mechanical support and then transferred onto a carrier substrate for convenient handling during the subsequent fabrication processes. The carrier substrates can be, for example, materials capable of withstanding the subsequent fabrication processes, such as a semiconductor wafer or glass. Between exemplary **FIGS. 2A to 2B**, the top surface **211** of the die **201** containing the IC chips is planarized by uniformly etching the passivation layer using reactive-ion etching (RIE).

Next, as shown in exemplary **FIG. 2C**, the individual IC chips on the die **201** are separated by performing dry etching in RIE for front-end-of-line (FEOL) **201a**, back-end-of-line (BEOL) **201b**, and buried oxide (BOX) **201c** to form vertical trenches **202** around the active areas of the IC chips. For example and without limitation, the FEOL **201a** can refer to the first part of the IC chips that contain individual components, such as transistors, resistors, and capacitors. The BEOL **201b** can refer to the second part of IC chips where these individual components get interconnected with metalization layers. The BOX **201c** can refer to an insulator layer made of oxide and buried in the silicon wafer of SOI CMOS processes. As shown in exemplary **FIG. 2D**, the sidewalls of the IC chips in their respective vertical trenches **202** can be passivated. Passivation of the sidewalls can include for example, depositing conformal parylene to fill the vertical trenches **202** thereto to permit biocompatibility of the IC chips with biological tissues.

An anisotropic conductive adhesive can then be deposited onto the surface **211** of the IC chips, as illustrated in exemplary **FIG. 2E**. For example and without limitation, the adhesion material selected and deposited can conduct vertically only and not laterally in order to avoid shorting adjacent pads/electrodes. Following the deposition of the adhesion layer

203, the fabrication process of the presently disclosed subject matter can include integrating piezoelectric transducers onto the IC chips. Such integration is illustrated in exemplary **FIG. 2F**. Each individual IC chip contains an input pad and a ground pad, and a piezoelectric transducer has a top electrode and a bottom electrode between which the electrical energy converted from the incoming ultrasound waves is produced. The integration of a piezoelectric transducer with an IC chip can include the electrical connections of the bottom transducer electrode with the chip input pad and the top transducer electrode with the chip ground pad. For example and without limitation, a piece of piezoelectric transducer **204** that completely covers the top surface **211** of the die **201** containing the IC chips can be placed on top of the adhesion layer **203** to make the electrical connection between the input pads of the IC chips and the corresponding bottom transducer electrodes.

As shown in exemplary **FIG. 2G**, the piezoelectric transducer **204** is then patterned with the AZ4620 photoresist as an etch mask and subsequently etched in RIE to expose the ground pads of the IC chips. Other suitable patterning techniques are also within the scope of the presently disclosed subject matter. The top transducer electrodes can then be electrically connected to the chip ground pads via deposition of titanium metal for biocompatibility, followed by a lift-off process to remove unwanted metallization, as illustrated in exemplary **FIG. 2H**. The fabricated devices **100** can be released from the carrier substrate by selectively etching away the backing layer, as illustrated in exemplary **FIG. 2I**. The released devices can be transferred to deionized water for rinsing. Such fully fabricated USID sensing tags **100** can be either dried or can be implanted/injected into a sample of interest using a syringe.

As disclosed herein, and with reference to exemplary **FIG. 3**, the USID sensing tag can include an IC chip configured in accordance with the disclosure herein. For example and without limitation, the IC chip herein disclosed and illustrated in exemplary

FIG. 3 can be implemented in a 180-nm CMOS technology provided by Taiwan Semiconductor Manufacturing Company (TSMC). An exemplary overall circuit block diagram **300** of the IC chip is depicted by way of example and explanation only, and not limitation. The customized IC chip can include a front-end charge pump **320**, coupled to receive the AC input signal **311** from the integrated piezoelectric transducer **310** and is configured to produce a DC output. The IC chip further includes a relaxation oscillator **330**, coupled to the charge pump **320**. The relaxation oscillator **330** can be configured to receive power from the DC output generated in the charge pump **320** and produce a periodic oscillation signal. The IC chip further includes a modulator **340**, coupled to the relaxation oscillator **330**. The modulator can be configured to receive the oscillation signal from the relaxation oscillator and accordingly modulate the input impedance of the IC chip.

The front-end charge pump **320** can be configured to convert the input AC signal into a DC voltage to power the relaxation oscillator **330** as shown in exemplary **FIG. 3**. A circuit diagram for the charge pump is provided in **FIG. 4**. When the AC input **411** from the piezoelectric transducer is negative, the current I_1 **401** charges C_1 **402** to the peak value of the input through D_1 **403**; when the input is positive, in addition to the existing voltage across C_1 **402**, the current I_2 **405** charges C_2 **406** to double the peak voltage of the input through D_2 **407**, creating a voltage that is twice the peak value of the AC input **411** at the DC output **421**. Additionally or alternatively, C_2 **406** can also be used as a storage capacitor to store the energy accumulated from the input source.

A circuit diagram for the relaxation oscillator **330**, with reference to exemplary **FIG. 3**, is provided in **FIG. 5**. The relaxation oscillator **330** of the presently disclosed subject matter can include three inverters, U_1 , U_2 and U_3 , a capacitor C_1 and a resistor as illustrated by way of example in **FIG. 5**. Such circuitry can be configured to produce a specific oscillation frequency depending on the value of the capacitor and resistor.

Additionally, the resistor in the oscillator of exemplary **FIG. 5** can be implemented using the cathodes of two diodes D_1 and D_2 connected in series. These diodes can provide a high resistance on the order of hundreds of Giga Ohms ($G\Omega$), and therefore can produce an oscillation frequency of a few Hz. The measured oscillation frequency of the present
5 oscillator is approximately 1.8Hz and measured power consumption is 3.24nW.

With reference to exemplary **FIG. 3**, a modulator **340** can be configured to actively modulate the input impedance of the IC chip. As illustrated in exemplary **FIG. 6**, the modulator **340** can include a single n-channel metal-oxide-semiconductor field-effect transistor (MOSFET) Q_1 . The MOSFET includes at least three terminals, including a gate, a
10 source, and a drain, where the gate is connected to and controlled by the output of the relaxation oscillator **330**, the source is connected to ground and the drain is connected to the ultrasonic AC input **311**. Such configuration can cause the input impedance of the USID sensing tag to appear as solely the piezoelectric transducer **310** when the oscillator output is in the low state and as a parallel combination of the piezoelectric transducer **310** and the
15 capacitance between the drain and source of the MOSFET when the oscillator output is in the high state. The modulator **340** of exemplary **FIG. 3** is thereby implementing a standard amplitude-shift keying (ASK) scheme to alter the echo reflected from the piezoelectric transducer **310** during excitation. For example and without limitation, the size of the MOSFET can be $2\mu\text{m} / 450\text{nm}$ (length / width) so that the impedance at the ultrasonic input
20 **311** can be decreased by a factor of approximately three when the oscillator output changes from the low state to the high state, thereby modulating the reflected ultrasound waves back to the ultrasound imaging equipment. By way of example only, and not limitation, the B-mode ultrasound image scan can be used to confirm the functionality of the presently disclosed subject matter. When a USID sensing tag is functional upon excitation, the tag
25 appears as a blinking dot in the ultrasound image as its brightness periodically changes

according to the modulation of the reflected ultrasound echo signals back to the imaging equipment.

Exemplary **FIG. 7** shows a diagram of the die containing the IC chips implemented in a 180-nm CMOS technology provided by TSMC.

5 As herein disclosed, the commercial ultrasound imaging equipment utilized to provide ultrasound waves to the USID sensing tags can be designed for medical imaging of small animals in a preclinical setting, including, but not limited to, cardiac, vascular, tumor and molecular imaging for mouse, rat, rabbit and zebra fish. Additionally, the size and power requirement of the micron-scale USID sensing tags matches the spatial resolution and energy
10 intensity of the ultrasound waves in the chosen 30MHz – 50MHz range from the imaging equipment. Also, the USID sensing tags can potentially incorporate sensors for in-vivo acquisition of various physiological signals. Therefore, the USID sensing tags of the presently disclosed subject matter can be implanted or injected into various organs in several kinds of small animals and excited/imaged by the commercial ultrasound imaging equipment
15 for numerous applications and studies. With different kinds of embedded sensors, applications of these tags include, but not limited to, monitoring electrophysiology in the brain through the vasculature, probing intracellular activities by examining concentrations of certain molecules, and detecting biogenic amine levels in the gastrointestinal tract to study communication between the microbiota and the brain.

20 The description herein merely illustrates the principles of the disclosed subject matter. Various modifications and alterations to the described embodiments will be apparent to those skilled in the art in view of the teachings herein. Accordingly, the disclosure herein is intended to be illustrative, but not limiting, of the scope of the disclosed subject matter. Moreover, the principles of the disclosed subject matter can be implemented in various

configurations of hardware, and are not intended to be limited in any way to the specific embodiments presented herein.

CLAIMS

1. An ultrasound identification sensing tag powered by ultrasound signals from commercial ultrasound imaging equipment, comprising:

a piezoelectric transducer configured to convert mechanical energy of said ultrasound signals into alternating-current (AC) electrical energy;

an integrated circuit chip, electrically coupled to said piezoelectric transducer, having circuitry configured to at least receive said electrical energy for power and to actively modulate an input impedance thereof;

wherein said piezoelectric transducer includes at least polyvinylidene fluoride (PVDF) or lead zirconate titanate (PZT); and

wherein said integrated circuit chip and said piezoelectric transducer are integrated.

2. The ultrasound identification sensing tag of claim 1, wherein said ultrasound signals from commercial ultrasound imaging equipment comprise ultrasound waves within a range of 30MHz and 50MHz.

3. The ultrasound identification sensing tag of claim 1, wherein said integrated circuit chip is passivated by parylene.

4. The ultrasound identification sensing tag of claim 1, wherein said integrated circuit chip further comprises:

a charge pump, coupled to receive said alternating-current electrical energy from said piezoelectric transducer, configured to produce a direct-current (DC) output voltage;

a relaxation oscillator, coupled to said charge pump, configured to receive said DC output voltage from said charge pump and generate an oscillation signal; and

a modulator, coupled to said relaxation oscillator, configured to receive said oscillation signal from said relaxation oscillator and modulate said input impedance of said integrated circuit chip.

5. The ultrasound identification sensing tag of claim 4, wherein said charge pump further comprises two capacitors and two diodes.

6. The ultrasound identification sensing tag of claim 4, wherein said relaxation oscillator further comprises three inverters, one capacitor, and two diodes.

7. The ultrasound identification sensing tag of claim 4, wherein said modulator further comprises an n-channel metal-oxide-semiconductor field-effect transistor (MOSFET) having a gate, said gate being controlled by said oscillation signal.

8. The ultrasound identification sensing tag of claim 4, wherein said modulator is further configured to actively modulate said input impedance of said integrated circuit chip to cause a periodic impedance change seen by the said piezoelectric transducer, said periodic impedance change detectable by said piezoelectric transducer.

9. The ultrasound identification sensing tag of claim 8, wherein said periodic impedance change detectable by said piezoelectric transducer causes a periodic change in the acoustic impedance mismatch between said ultrasound identification sensing tag and one or more surrounding tissues, said acoustic impedance mismatch creating an echo signal transmitted from said piezoelectric transducer and returned back to said commercial ultrasound imaging equipment; wherein said echo signal forms a brightness-mode (B-mode) image in said commercial ultrasound imaging equipment and causes a periodic brightness change of said sensing tag in said brightness-mode (B-mode) image, indicating the said sensing tag is functional.

10. The ultrasound identification sensing tag of claim 1, wherein said sensing tag further comprises sensors for receiving one or more physiological signals from a biological tissue to enable applications including, but not limited to, real-time pH sensing, drug delivery and controlled release, chemical and biological activity detection, and digestion monitoring of small animals.

11. A method for fabricating one or more ultrasound identification sensing tags, comprising:

thinning a die comprising one or more integrated circuit chips;
placing said die in an aluminum backing layer;
transferring said die to a carrier substrate;
planarizing a top surface of said die;
separating said one or more integrated circuit chips on said die;
passivating one or more integrated circuit chips on said die;
depositing an adhesion layer onto said top surface of said die;
integrating one or more piezoelectric transducers onto said one or more integrated circuit chips; and
releasing fully fabricated one or more ultrasound identification sensing tags from said carrier substrate.

12. The method of claim 11, wherein said thinning further comprises performing a sequential combination of mechanical grinding followed by deep reactive-ion etching (DRIE).

13. The method of claim 11, wherein said planarizing further comprises uniformly etching the passivation layer of said die using reactive-ion etching (RIE).

14. The method of claim 11, wherein said separating further comprises performing reactive-ion etching (RIE) on said die to form vertical trenches around active areas of each of said integrated circuit chips.

15. The method of claim 14, wherein said reactive-ion etching (RIE) comprises etching the front-end-of-line (FEOL), the back-end-of-line (BEOL) and the buried oxide (BOX) of said die.

16. The method of claim 11, wherein said passivating further comprises depositing parylene to fill said vertical trenches for biocompatibility.

17. The method of claim 11, wherein said depositing said adhesion layer further comprises depositing an anisotropic conductive adhesive.

18. The method of claim 11, further comprising connecting one or more bottom transducer electrodes to one or more corresponding input pads of said integrated circuit chips, patterning one or more top transducer electrodes, and connecting said top transducer electrodes to one or more corresponding ground pads of said integrated circuit chips via metal deposition.

19. The method of claim 11, further comprising releasing said sensing tags from said carrier substrate by selectively etching away said backing layer.

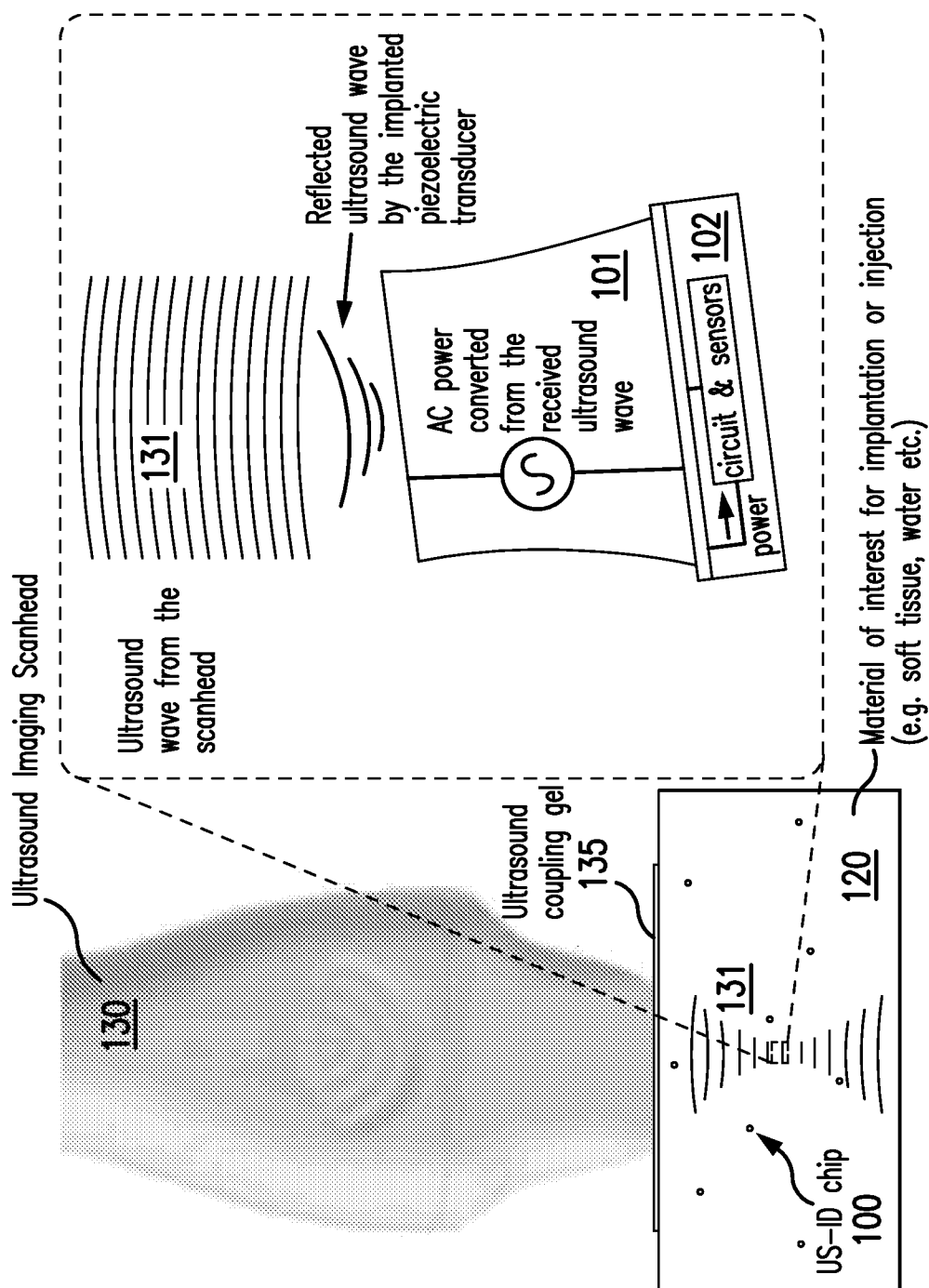


FIG. 1

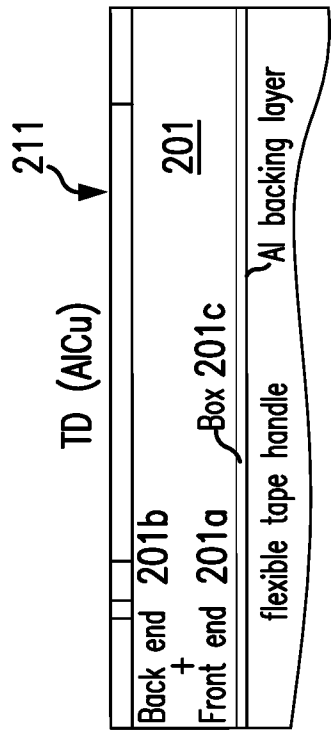


FIG. 2A

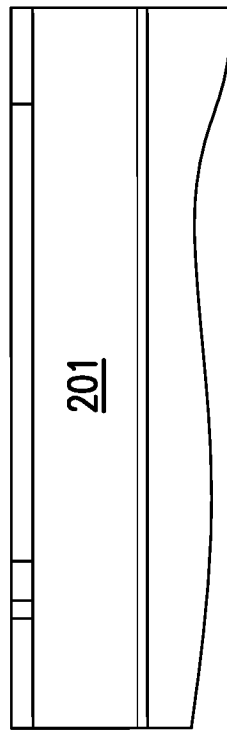


FIG. 2B

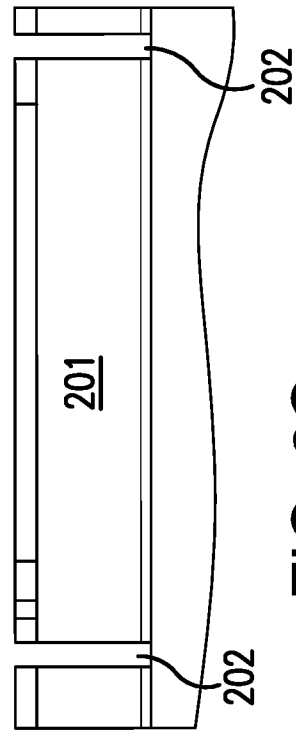


FIG. 2C

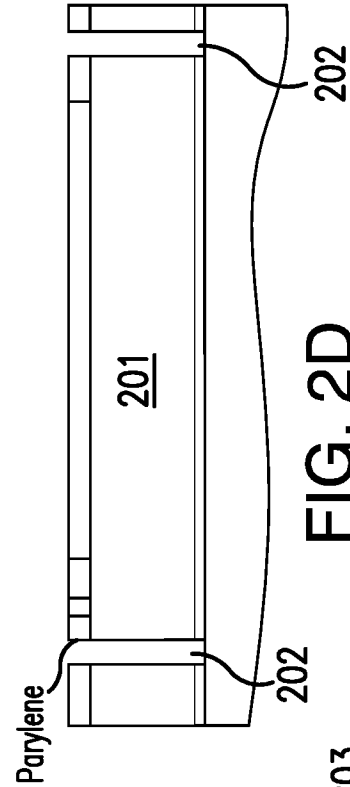


FIG. 2D

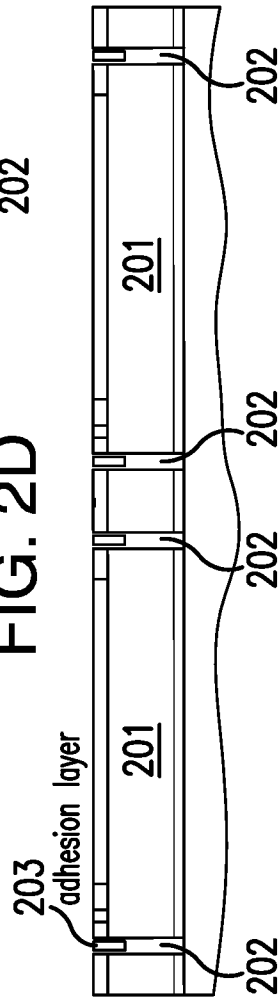


FIG. 2E

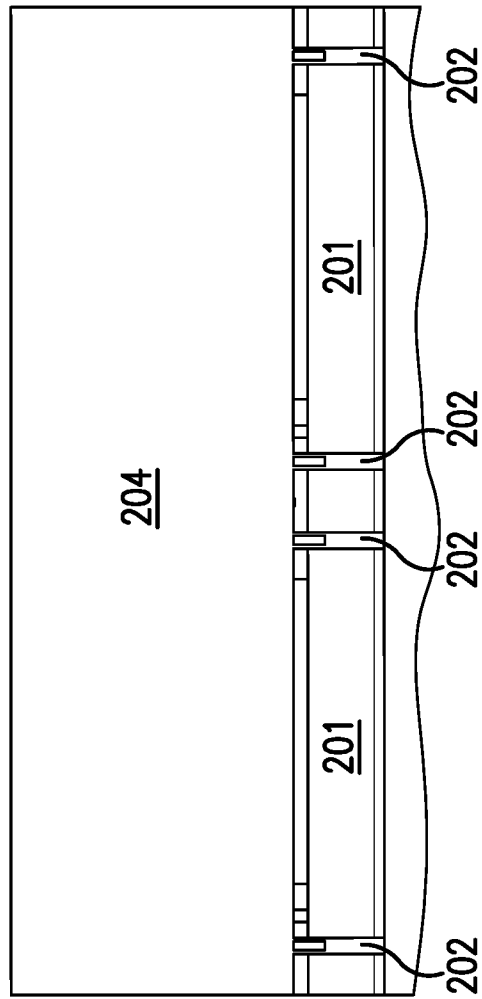


FIG. 2F

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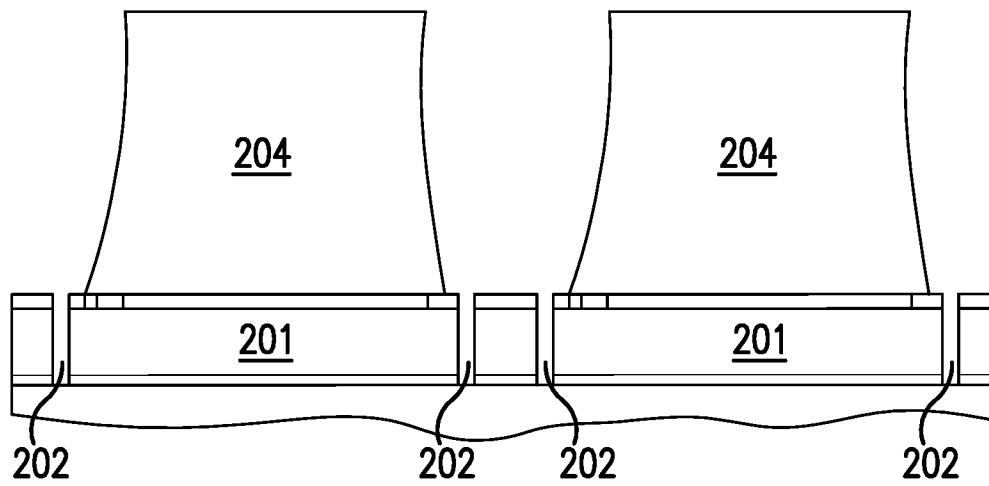


FIG. 2G

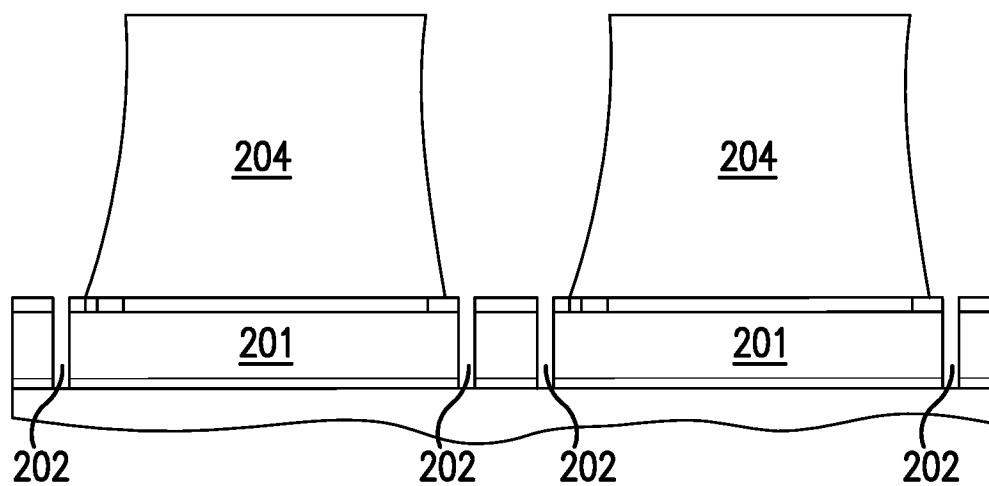


FIG. 2H

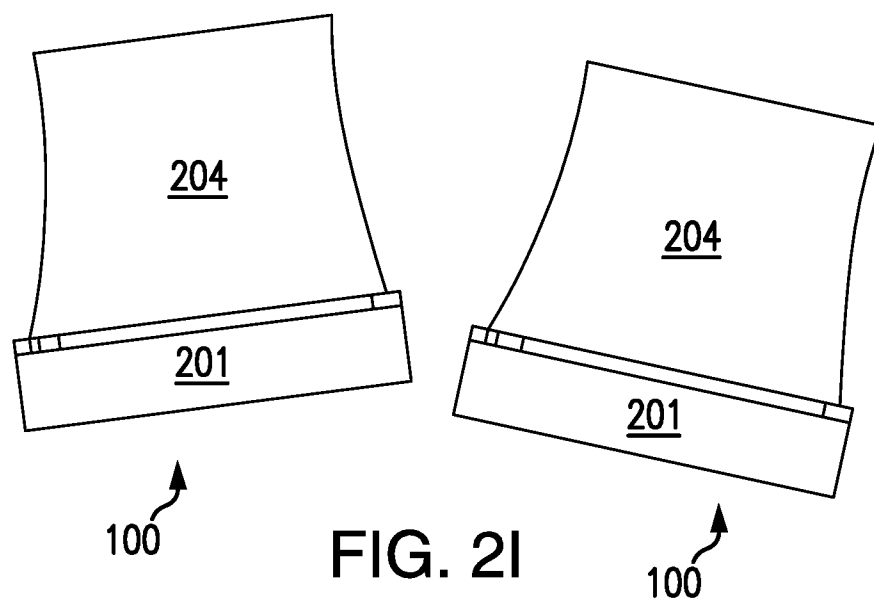


FIG. 2I

SUBSTITUTE SHEET (RULE 26)

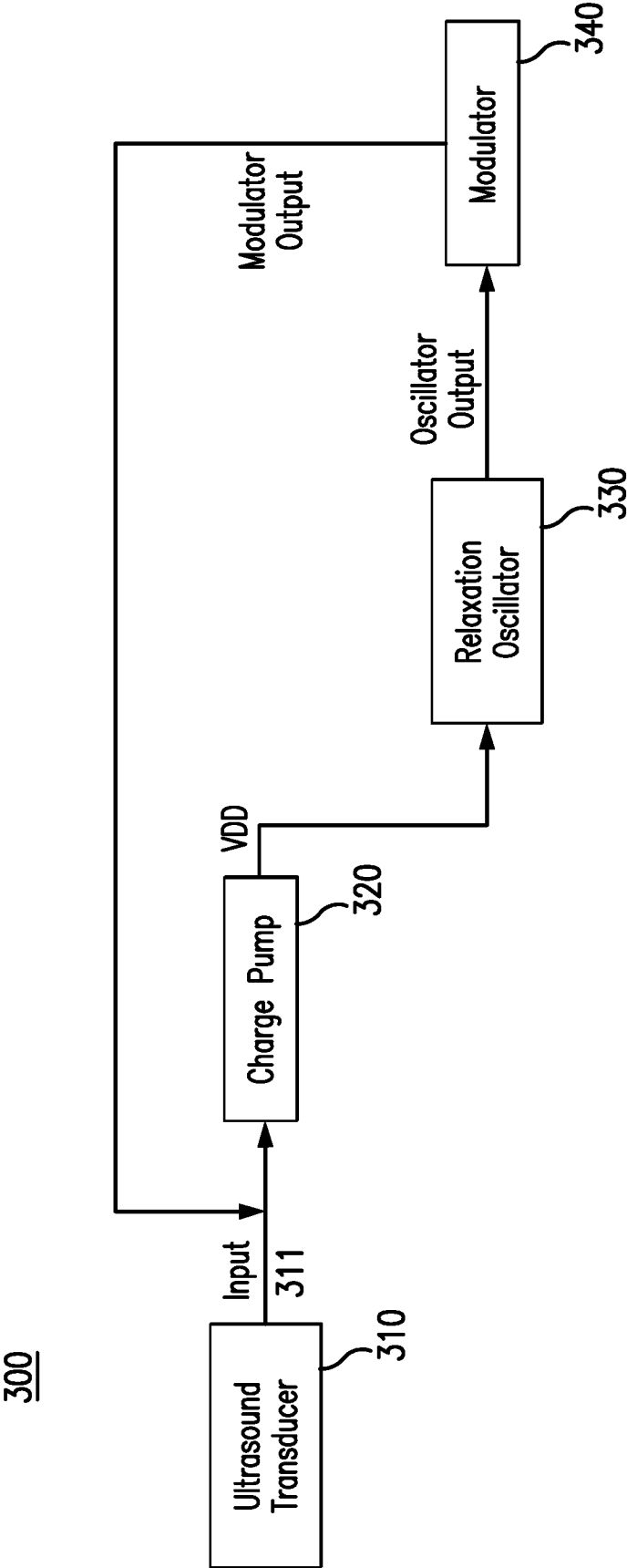


FIG. 3

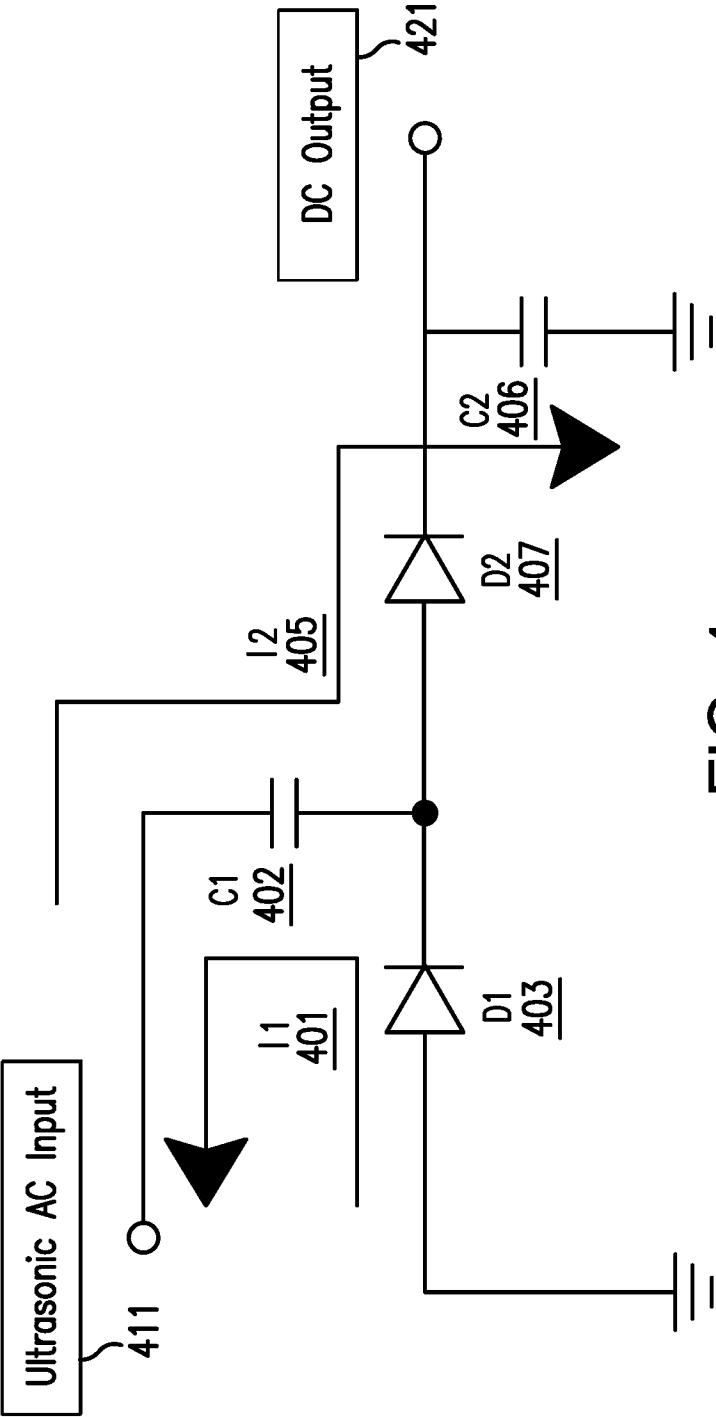


FIG. 4

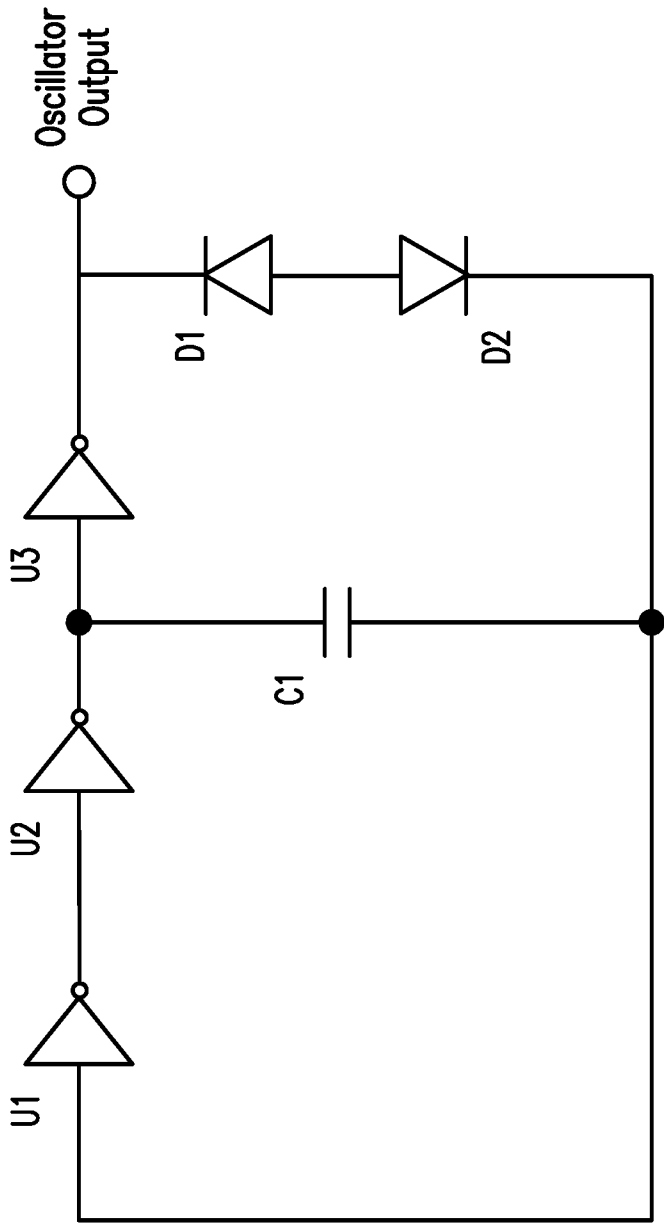


FIG. 5

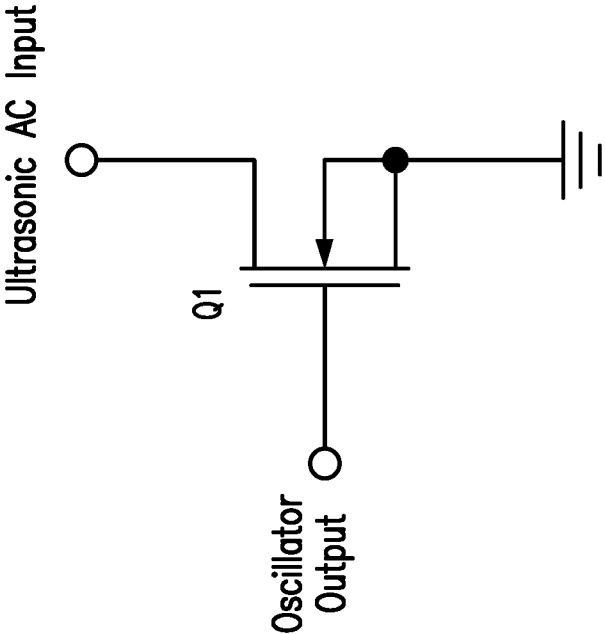


FIG. 6

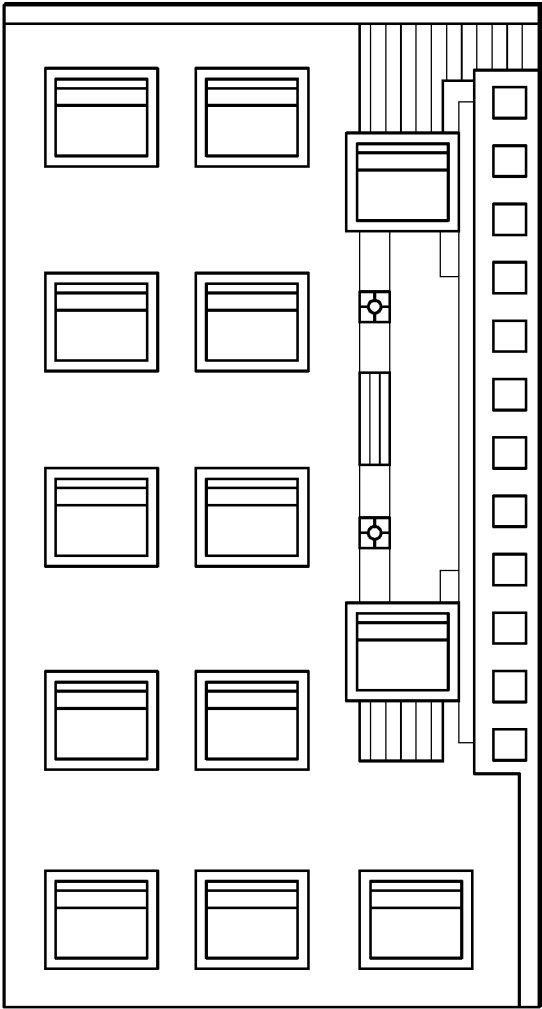


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 16/50165

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - A61B 8/00; H04B 11/00; H04R 17/00 (2016.01)

CPC - A61B 5/0031, 2560/0214, 2560/0219

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)

CPC: A61B 5/0031, 2560/0214, 2560/0219;

IPC(8): A61B 8/00; H04B 11/00; H04R 17/00 (2016.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

CPC: A61B 5/0026, 5/0028, 5/0031, 8/00, 2560/0214, 2560/0219; H04B 11/00; A61K 9/0009, 9/0097; H04R 17/00

USPC: 600/437; 604/890.1, 891.1; 367/157, 180; IPC(8): A61B 8/00; H04B 11/00; H04R 17/00 (2016.01)

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

Google (web, scholar, patents), PatBase

Search terms: Ultrasound, ultrasonic, acoustic, vibration, tag, implant, piezo, piezoelectric, pzt, pvdf, convert, harvest, impedance, modulator, oscillator, charge pump, echo, brightness

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y --- A	US 2011/0178578 A1 (PORAT et al.) 21 July 2011 (21.07.2011), para [0015], [0018], [0035], [0036], [0048], [0087], [0100], [0103], [0112], [0133], [0153], [0187]	1-3, 10 ----- 4-9
Y --- A	US 2012/0041310 A1 (TOWE) 16 February 2012 (16.02.2012), Abstract; para [0039], [0066], [0068]	1-3, 10 ----- 4-9
Y --- A	US 5,423,334 A (JORDAN) 13 June 1995 (13.06.1995), col 15, ln 33-49; col 16, ln 13-21	3
Y --- A	US 2014/0309503 A1 (ARNESON et al.) 16 October 2014 (16.10.2014), para [0080], [0083], [0089]	4-9

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

* Special categories of cited documents:

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

27 December 2016

Date of mailing of the international search report

05 JAN 2017

Name and mailing address of the ISA/US

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 16/50165

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

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

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I: Claims 1-10 directed to an ultrasound identificatino sensing tag.

Group II: Claims 11-19 directed to fabricating an ultrasound identification sensing tag.

---Please see continuation sheet---

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-10

Remark on Protest

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

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 16/50165

Continuation of Box No. III -- Observations where unity of invention is lacking

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

Special Technical Features

Group I includes the special technical features of an ultrasound identification sensing tag powered by ultrasound signals from commercial ultrasound imaging equipment, comprising: a piezoelectric transducer configured to convert mechanical energy of said ultrasound signals into alternating-current (AC) electrical energy; an integrated circuit chip, electrically coupled to said piezoelectric transducer, having circuitry configured to at least receive said electrical energy for power and to actively modulate an input impedance thereof; wherein said piezoelectric transducer includes at least polyvinylidene fluoride (PVDF) or lead zirconate titanate (PZT) not found in the other group.

Group II includes the special technical feature of a method for fabricating one or more ultrasound identification sensing tags, comprising: thinning a die comprising one or more integrated circuit chips; placing said die in an aluminum backing layer; transferring said die to a carrier substrate; planarizing a top surface of said die; separating said one or more integrated circuit chips on said die; passivating one or more integrated circuit chips on said die; depositing an adhesion layer onto said top surface of said die; and releasing fully fabricated one or more ultrasound identification sensing tags from said carrier substrate not found in the other group.

Shared Technical Features:

The only features shared by Groups I-II that would otherwise unify the groups, is the technical features of an ultrasound identification sensing tag and integrating a piezoelectric transducer with an integrated circuit chip.

However, these shared technical features do not represent a contribution over prior art, because the shared technical features are disclosed by US 5,833,603 A to Kovacs et al. (hereinafter Kovacs). Kovacs discloses an ultrasound identification sensing tag (col 6, ln 57 to col 7, ln 5 and col 7, ln 6-32) and integrating a piezoelectric transducer (106) with an integrated circuit chip (36, 40) (Fig. 8 and col 13, ln 41 to col 14, ln 17).

As the special technical features were known in the art at the time of the invention, this cannot be considered a special technical feature that would otherwise unify the groups.

Therefore, Groups I and II lack unity under PCT Rule 13.