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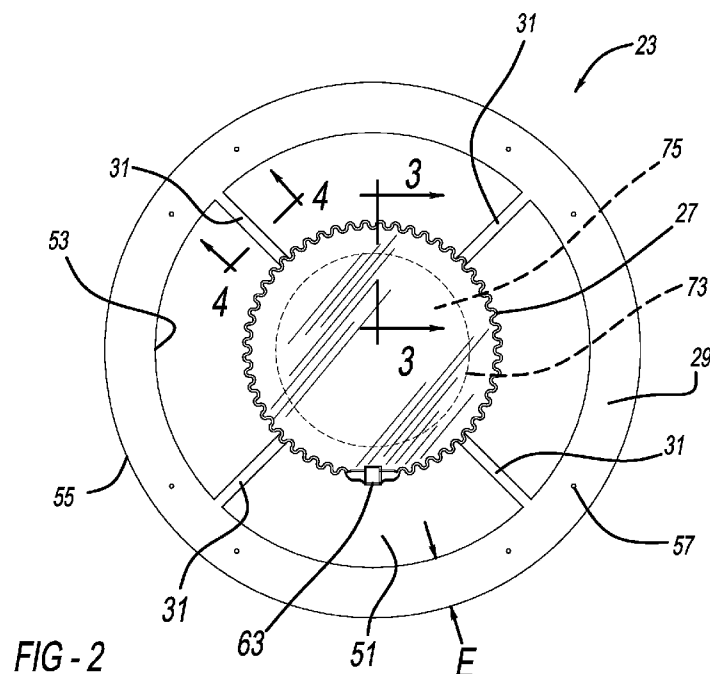
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(54) Title: INTRAOCULAR PRESSURE SENSOR



(57) Abstract: A pressure sensor system is provided. In another aspect, a wireless intraocular pressure sensor includes a deformable or stretchable inductor. A further aspect of an intraocular pressure sensing system includes a deformable inductor sized to contact an eye. Another aspect provides an organ pressure sending system including a passive inductor with a wavy, serpentine or undulating shape.



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INTRAOCULAR PRESSURE SENSOR

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application
5 No. 62/474,750 filed on March 22, 2017, which is incorporated by reference
herein.

BACKGROUND AND SUMMARY

[0002] The present disclosure relates generally to pressure sensors and
10 more particularly to a wireless intraocular pressure sensor system including a
deformable inductor.

[0003] Glaucoma is the second leading cause of blindness which is an
asymptomatic, progressive and irreversible disease that is usually associated
with elevated intraocular pressure. Most conventional constructions of intraocular
15 pressure sensors can be categorized into three general groups in terms of their
energy transferring mechanisms: active, passive, and radio-frequency- powered
devices.

[0004] Active devices traditionally employ application specific integrated
circuits that can store, process and transmit data. However, they make the
20 overall device large, heavy and inflexible. Furthermore, such active systems
typically require an integrated battery or power-receiving coil, which both add to
the weight and size of the device.

[0005] Traditional passive sensors require high precision surgery to anchor
the device to the iris. The fabrication process for such passive devices is
25 typically complex and expensive. Furthermore, such traditional passive sensors
require an external reading mechanism of an undesirably large size that
interferes with the vision of the patient thereby making it unsuitable for wearable
long term measurements.

[0006] Conventional radio frequency or electromagnetic coupled sensors
30 have employed variable capacitors to sense pressure. These variable
capacitors, however, require a pressurized reference chamber that has great
difficulty in sustaining its baseline pressure over time due to packaging
imperfections. This causes significant undesirable signal drift due to the leakage.

[0007] Exemplary prior intraocular pressure sensors are disclosed in U.S. Patent No. 9,289,123 entitled “Contact Lens for Measuring Intraocular Pressure” which issued to Weibel et al. on March 22, 2016, and U.S. Patent Publication No. 2016/0051144 entitled “Systems and Methods for Monitoring Eye Health” which published to Rickard et al. on February 25, 2016. Both of these are incorporated by reference herein. It is noteworthy that Weibel includes a considerable quantity of electronic components. Moreover, Rickard uses only capacitive sensing and requires surgical implantation into the eye.

[0008] In accordance with the present invention, a pressure sensor system is provided. In another aspect, a wireless intraocular pressure sensor includes a deformable or stretchable inductor. A further aspect of an intraocular pressure sensing system includes a deformable and variable inductor, within a ring-shaped carrier layer, sized to contact an eye. Another aspect provides an organ pressure sensing system including a passive inductor with a wavy, undulating or serpentine shape. In yet another aspect, a biomedical pressure sensor includes a deformable inductor having an undulating pattern along at least a majority of its length, a deformable outer ring spaced away from and surrounding the inductor, and elongated connectors or arms spanning between the inductor and an outer ring, with the connectors being radially elongated and causing deformation of an adjacent portion of the inductor when the outer ring is deformed or moved due to internal body pressure. A method of making and/or using a wireless intraocular pressure sensor, including a deformable inductor, is also provided.

[0009] The present pressure sensor is advantageous over conventional devices. For example, the present pressure sensor functions as a passive strain gauge that synergistically serves as both a pressure sensitive element and a wireless communications interface. It advantageously does not obstruct the vision of the patient, as compared to conventional cornea-mounted devices. Furthermore, in one exemplary construction, the present system is intended to be a temporarily worn device that is easily removable or dissolvable after a predetermined period of time, and does not require surgical *in vivo* implantation or removal. Another exemplary construction *in vivo* implants only a passive sensor for use with a portable or temporarily adhered reader. Moreover, the present system advantageously includes only minimal electronic components, such as a single capacitor, located in the sensor device inserted onto the eye;

this provides a much lighter weight and lower cost device which does not obstruct the patient's vision. Additional advantages and features of the present system and method will become apparent from the following description and appended claims, taken in conjunction with the associated drawings.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Figure 1 is a perspective view showing a first embodiment of the present intraocular pressure sensor system as worn on a patient;

10 **[0011]** Figure 2 is a front elevational view showing the first embodiment of an intraocular pressure sensor of the present system;

[0012] Figure 3 is a cross-sectional view, taken along line 3 – 3 of Figure 2, showing the first embodiment present intraocular pressure sensor;

[0013] Figure 4 is a cross-sectional view, taken along line 4 – 4 of Figure 2, showing the first embodiment present intraocular pressure sensor;

15 **[0014]** Figure 5 is a longitudinal sectional view, taken along line 5 – 5 of Figure 3, showing the first embodiment present intraocular pressure sensor;

[0015] Figure 6 is a diagrammatic and exploded perspective view showing the first embodiment present intraocular pressure sensor system;

20 **[0016]** Figure 7 is a cross-sectional view showing the first embodiment present intraocular pressure sensor on an eye;

[0017] Figure 8 is a circuit diagram of the first embodiment present intraocular pressure sensor system;

25 **[0018]** Figure 9A – H are a series of cross-sectional views showing a manufacturing process for the present intraocular pressure sensor for all embodiments;

[0019] Figure 10 is a front elevational view showing an alternate embodiment of the present intraocular pressure sensor;

[0020] Figure 11 is a cross-sectional view, taken along line 11 – 11 of Figure 10, showing the alternate embodiment intraocular pressure sensor;

30 **[0021]** Figure 12 is a front-elevational view showing another alternate embodiment intraocular pressure sensor system;

[0022] Figure 13 is a front elevational view showing a second embodiment of an intraocular pressure sensor of the present system;

[0023] Figure 14 is a cross-sectional view showing the second embodiment present intraocular pressure sensor on an eye; and

[0024] Figure 15 is a perspective view showing a third embodiment of a cardiovascular pressure sensor system.

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DETAILED DESCRIPTION

[0025] A first embodiment of an intraocular pressure sensing system 21 is shown in Figures 1 – 8, and includes an intraocular pressure sensor 23 and a reader 25. Sensor 23 includes a sensing and transmitting coil assembly 27, an
10 outer ring 29 and a plurality of connecting arms 31 spanning between the spaced apart coil assembly 27 and outer ring 29. Coil assembly 27 has a looped metallic inductor 33 at least partially encapsulated within a protective polymeric layer or casing 35. Inductor 33 is preferably made from layers of titanium and copper, titanium and gold, or an alloy thereof. Alternately, other metallic or conductive
15 polymeric materials may be employed although they may not be as advantageous.

[0026] Inductor 33 and protective layer 35 have an undulating, serpentine or wave-like shape along a curved length thereof, defined by alternating peaks and valleys with curved diagonal walls connecting therebetween. As will be
20 described in greater detail hereinafter, the undulating shape allows inductor 33 to be deformed and stretchably expanded at any point therealong. Figure 5 illustrates an increased width A of the inductor at each peak and valley which is greater than width B at each of the diagonal connecting walls. This effectively adds increased material at the peak and valley areas which are more prone to
25 fracture when expanded or deformed. However, an eye-facing inner surface 41 and an opposite outer surface 43 of inductor 33 are preferably substantially flat. Furthermore, the corresponding eye-facing inner surface 45 and opposite outer surface 47 of protective layer 35 are preferably substantially flat, but for optionally curved corners.

[0027] At least three and more preferably at least four connecting arms 31
30 are spaced away from each other with open gaps 51 therebetween. Each connecting arm 31 is radially elongated away from a center point of sensor 23. Moreover, each connecting arm 31 is integrally and directly connected to an outer periphery of protective layer 35 of sensor 27 and to an inside diameter surface 53

of outer ring 29. Each connecting arm 33 is preferably at least five times as long as wide C and at least twice as wide C as thick D . This dimensional arrangement allows connecting arms 31 to have a partially spherical or curved side view shape between their opposite ends to match the eye's shape. This dimensional configuration also allows for torsional flexure with minimal linear or radial stretch of the connecting arms. Notwithstanding, these exemplary dimensions may be varied.

[0028] Outer ring 29 preferably has a circular or arcuate outer periphery 55. A width E of outer ring 29 is preferably at least five times width C of each connecting arm 31 and at least ten times that of coil assembly 27. Notwithstanding, these exemplary dimensions may be varied. Outer ring 29 and coil assembly 27 are coaxial with gaps 51 therebetween. Multiple apertures 57 are disposed through the thickness of outer ring 29 for mechanically receiving and interlocking with a biocompatible adhesive applied to temporarily hold outer ring 29 to a sclera 59 of eye 61. The polymeric material for outer ring 29, connecting arms 39 and protective layer 35 is preferably Parylene-C (obtained from Parylene Coater-Specialty Coating System as PDS 2010), Sylgard[®] 184 Silicone Elastomer (obtained from Dow Corning), Polymethyl Methacrylate (obtained from MicroChem Corporation)) or the like.

[0029] A single electrical component, preferably a capacitor 63, is electrically connected to ends of inductor 33 and secured to sensing coil assembly 27. This is preferably the only electronic component directly attached to sensor 23, such that a battery, microprocessor and other solid state electrical components are not required, thereby saving weight and reducing cost.

[0030] The placement of sensor 23 relative to an organ, specifically a patient's eye 61, can best be observed in Figures 2 and 7. An inner surface 71 of outer ring 29 is temporarily mounted to sclera 59 by a dissolvable adhesive such as a hydrogel based adhesive. Inner surface 71 may optionally have a partial dome shape to conform to the sclera. Connecting arms 31 and sensing coil assembly 27, however, are free of an adhesive and allowed to move relative to eye 61. Sensing coil assembly 27, connecting arms 31 and outer ring 29 are all external to and outside of a periphery of a cornea 73 of eye 61. Nevertheless, an optional dissolvable polymeric film 75, of a generally dome-like shape, spans between an inside edge of sensor coil assembly 27 and initially spans across

cornea 73. This optional central film 75 is simply intended to add temporary supporting structure to the thin and deformable sensing coil assembly 27 during user or doctor insertion onto the eye and is intended to dissolve away within a day or two thereafter such that there is an unobstructed central opening over the cornea during normal sensing use. Outer ring 29, connecting arms 31, protective layer 35 and optional central film 75 are all substantially transparent.

[0031] Referring now to Figures 1, 6 and 8, reader 25 is preferably mounted to eyeglasses 81 which include transparent lenses 83, a frame 85 and earpieces 87. A reading coil or wire 91 is encapsulated within or adhered to an inside surface of eyeglass frame 85 generally surrounding each lens 83. Ends of the looped reading coil 91 are electrically connected to an electrical circuit 93 including a battery 95 for a wearable/portable reader or other power supply accessed through a wall outlet plug for a stationary reader, a signal generator voltage source (V_{SG}), a signal generator internal resistor (R_G), and a measurement resistor (R_M). In the circuit diagram, reading coil 91 is shown as a receiver coil impedance inductor (Z_r). Further in the circuit diagram of Figure 8, constant capacitor 63 is shown as C_S , a parasitic resistor function of the inductor is shown as R_S , and variable inductor 33 is illustrated as L_S .

[0032] Periodic electromagnetic transmissions are sent from the reader coil to the passive sensor coil to activate a resonant frequency of the sensor coil. This resonant frequency is based on the geometries of the inductor and capacitor, and has an exemplary frequency of 100 MHz to 1 GHz, which can be varied depending on the detectable frequency range of the impedance analyzer. Readout signals of the reader coil are impedance amplitude and phase over this frequency range to characterize the resonant frequency, where a phase dip is observed if the inductor is deformed. The phase dip is an indicator of the resonant frequency such that when the sensing inductor is deformed in response to pressure variation, a frequency shift of this phase dip can be detected.

[0033] Referring now to Figures 2 and 6 – 8, if intraocular pressure outwardly bulges or expands sclera 59 of eye 61 then outer ring 29 of sensor 23 will move off its nominal inner surface 71 position and/or radially move from its nominal circular position. This will move at least one of the adjacent connecting arms 31 in a linear and/or torsional manner. This movement of connecting arm 31 will subsequently deform, flex or circumferentially expand inductor 33 away

from its nominal free position which will accordingly change an inductance value received by reader coil 91 from inductor 33. The sensor serves as a planar and circular LC passive resonator that has a constant capacitor and a stretchable variable inductor. The self-inductance of the inductor, the parasitic capacitance between the segments, and the Q-factor are all changeable by the expansion of the sensor diameter. In addition, the mutual inductance between the sensing coil and reader coil will also change as the sensing coil deforms. This phenomenon is employed to measure the strain and the eye tissues induced by intraocular pressure elevation. Accordingly, the change of self-inductance in parasitic capacitance results in the change of resonance frequency of the LC loop. Therefore, the pressure variance can be read by the impedance analyzer through a frequency drift. The resultant output from impedance analyzer 93 of reader 25 is transmitted via communications transmitter 97 to a handheld or stationary computer device, through a Bluetooth standard, a Wi-Fi standard, an RFID standard, a ZigBee standard or the like. This sensor deformation provides an advantageous method of use.

[0034] A preferred manufacturing or fabrication process for at least the sensing coil assembly 27 portion of sensor 23 is illustrated in Figures 9A – H. Two masks are employed. As shown in Figure 9A, polymer 35 is deposited in a chemical vapor deposition process. First, a glass wafer or substrate 101 is coated with five μm of Parylene-C polymer 35, a twenty nm layer of titanium and a 700 nm layer of copper, 103 and 105 respectively, which will become inductor 33. This is shown in Figure 9B. Second, metallic layers 103 and 105 are evaporated using a thermal evaporator. A photoresist layer 107 or first mask is used to pattern the undulating shape using ultraviolet photolithography and thereafter wet-etching as illustrated in Figures 9C and 9D. Third, photoresist layer 107 is subsequently added on top of the copper layer 105. Fourth, surface mounted capacitor 63 (see Figure 2) is soldered to the end contacts of inductor 33 using silver epoxy. Fifth, Figure 9E illustrates applying another five μm polymeric coating at 109 to fully encapsulate the inductor layers. Sixth, Figure 9F shows a layer of aluminum 111 deposited on top of outermost polymeric layer 109 and patterned using a second photoresist layer mask to form an aluminum mask that protects the sealed metallic inductor core during subsequent plasma dry etching of the polymeric casing to create the trimmed form shown in Figure

9G. Finally, Figure 9H shows the completed sensing coil assembly 27 separated from the glass substrate and with the aluminum mask removed. The connecting arms and outer ring are also simultaneously formed in an integral and one piece manner with the polymeric encapsulating layers.

5 **[0035]** The completed inductor preferably has a thickness F (see Figure 3) of approximately 500 – 900 nm and more preferably 720 nm. A thickness G of protective polymeric layer 35 on each inner and outer surface is approximately 3 – 10 μm and more preferably 4 – 5 μm . Alternately, the inductor and/or polymeric layers can be two-dimensionally or three-dimensionally printed. Furthermore, the
10 polymeric material may alternately be coated onto the metallic inductor by spinning, chemical vapor deposition, dipping at room temperature, or spraying. Moreover, the inductor may alternately be produced by using 2-D printing, e-beam evaporations, vapor deposition, sputtering, electroplating or electroless plating.

15 **[0036]** Reference should now be made to Figures 10 and 11 for an alternate embodiment of the present pressure sensor. In this construction, a generally annular sensing coil assembly 131 includes an undulating inductor coil 133 at least partially encapsulated in a protective polymeric casing or layer 143. Connecting arms and an outer ring such as in the prior embodiment are also
20 included although not presently shown. Ends 135 and 137 of sensing coil assembly 131 extend past each other such that distal segments 139 overlap each other in a stacked manner with an adhesive therebetween to secure together internal facing surfaces 141 thereof.

25 **[0037]** If an adhesive is not employed in a variation thereof, the integrated sensing inductor and capacitor can be microfabricated using a metal-polymer sandwich. Such can be manufactured by: first, depositing a polymeric bottom layer; second, depositing and patterning a bottom metal plate layer of the capacitor; third, deposition and patterning of a polymeric dielectric layer on top of the metal plate; fourth, depositing and patterning a top metal plate layer; then
30 fifth, encapsulating the top capacitor plate within a polymeric material.

[0038] Polymeric layer 143 encapsulating inductor 133 serves as a predominantly non-conductive insulator between the overlapped ends of inductor 133 at overlapping segment 139. Thus, overlapping segment 139 functions as a capacitor integrated as a synergistic and multifunctional construction along with

the sensing inductance and signal transmitting antenna-like functions. The microfabricated version advantageously eliminates the capacitor assembly steps and improves device reliability and production yield. Accordingly, a separate capacitor component is not required. It should be appreciated that while it is preferred to use this integrated inductor and capacitor device for a wireless intraocular pressure sensor, it should also be appreciated that this device may alternately be applied to a variety of other types of biomedical sensors that are attached to or implanted in a patient.

[0039] Figure 12 illustrates yet another alternate embodiment biomedical pressure sensor 201. In this exemplary configuration, sensor system 201 includes a passive sensor 203 essentially the same as with the first embodiment of Figure 2, however, it is mounted to an internal patient-side or encapsulated within a patch 205. Patch 205 is preferably a flexible film or sheet of polymeric material with a pressure sensitive adhesive on the internal side thereof. Furthermore, a looped reading coil wire 207 is attached to one of the surfaces of patch 205 or encapsulated therein. Reading coil wire 207 coaxially surrounds inductor 209 and an outer ring 211 without directly contacting inductor 209. Impedance analyzer and communications circuitry 213 and associated electronics are electrically connected to reading coil wire 207 and mounted to an outside surface of patch 205. As shown in Figure 1, sensor system 201 is removably adhered to external skin area of the patient so as to sense blood pressure, heart rate, or other patient-induced movements which deform the outer ring, connecting arms 221 and the inductor.

[0040] An alternate design employs a wearable sensing watch with the impedance analyzing circuitry and a digital display constructed on an outside surface of a patch, which is electrically connected to a reading coil wire. The watch is wrist mounted by a strap, and includes a timekeeping clock circuit in addition to the reading circuit, but is otherwise like that shown in Figure 12. In this construction, there is no need for communications circuitry to transfer data to a separate reader.

[0041] A second major embodiment of an intraocular pressure sensing system 321 is shown in Figures 13 and 14, and includes an intraocular pressure sensor 323 used with the previously disclosed reader 25 (see Figure 1). Reader 25, however, includes an analog front-end circuit for impedance measurements

and a user friendly control panel or display, in addition to a conductive coil, a microprocessor controller and a power supply like a battery.

[0042] Sensor 323 includes a sensing and transmitting coil assembly 327 embedded in a donut shaped or ring-like carrier or protective layer 335. Protective layer 335 has concentric inner and outer edges 355 and 357, respectively. Coil assembly 327 has a looped metallic inductor 333 at least partially encapsulated within protective and insulating layer 335 which is polymeric. Inductor 333 is a variable inductor.

[0043] Inductor 333 has an undulating, serpentine or wave-like shape along a curved length thereof, defined by alternating peaks and valleys with curved diagonal walls connecting therebetween. The undulating shape allows inductor 333 to be deformed and stretchably expanded at any point therealong. The materials and manufacturing process for this exemplary inductor and protective layer can optionally be the same as for the first embodiment. Alternately, coil assembly 327 is optionally placed into a mold designed for the size and curvature of the cornea to which it will be applied. The mold is thereafter filled with a polymer (e.g., PDMA, PDMS or HEMA) and the material is polymerized by heating or exposure to UV light to create the desired final shape for carrier layer 335.

[0044] An eye-facing inner surface 341 and an opposite outer surface 341 of inductor 333 are preferably substantially parallel to each other and flat. Furthermore, the corresponding eye-facing inner surface 345 and opposite outer surface 347 of protective layer 335 are preferably substantially parallel to each other, and may optionally include curved corners and curved intersecting sides. Eye-facing inner surface 345 of protective layer 335 contacts against and is positioned over cornea 73 of eye 61 adjacent a periphery thereof. If intraocular pressure outwardly expands and stretches the cornea, this stretching will subsequently deform, flex or circumferentially expand inductor 333 away from its nominal free position which will accordingly change an inductance value received by the reader coil from inductor 333.

[0045] The electrical circuit function of the second embodiment organ sensing system 321 is similar to that shown in Figure 8. The present use of a variable inductor in an LCR tank, parallel resonance circuit for strain sensing is incorporated for intraocular organ pressure sensing. It employs a flexible and

stretchable conductive element which is achieved using serpentine geometry. The capacitance in series with the inductor is achieved on-chip and is a constant capacitor in the range of 5 picoFarads (for both the capacitor 363 in Figure 13 and 63 in Figure 2). The inductor diameter is near 11 millimeters that results in a variable inductor near 35 nano Henries. The parasitic resistance is below 10 ohms that results in a good quality factor. Furthermore, the mean resonance frequency of the LCR tank is near 500 Megahertz. It should be appreciated, however, that these specific exemplary values will be optimized for different organ applications, and therefore, may vary. The stretchable inductor is placed around the corneoscleral joint and the sensor stretches and changes the inductor's diameter when elevation of intraocular pressure changes the circumferential curvature of the cornea. The curvature change is transferred to the stretchable inductor partially through the carrier layer that holds and packages the inductor inside, without the need for supplemental hermetic packaging of electronics.

[0046] Another alternate embodiment is illustrated in Figure 15. This construction employs a pressure sensing system 421 including an *in vivo* organ pressure sensor 423 and an *ex vivo* reader 425. Sensor 423 has a sensing and transmitting coil assembly 427 embedded and encapsulated in an insulating polymeric protective carrier or layer 435. This layer 435 may have an inner edge defining a central opening or may be solid, continuously spanning across the central area as is illustrated. An elongated tail 436 may optionally extend from a peripheral and generally circular and arcuate outer edge 457 of layer 435.

[0047] Coil assembly 427 includes a looped or serpentine wavy metallic inductor, and a capacitor electronic component 463 attached thereto. Sensor 423 is passive, without a microprocessor or battery attached thereto. Layer 435 is adhesively bonded to an outside surface of a cardiovascular organ 481, such as a heart or blood vessel, by a bioadhesive or less preferably, sutured thereto.

[0048] Reader 425 is a handheld and portable impedance analysis unit or module (as illustrated) within a housing 483 containing a battery power supply, microprocessor, reading coil and electrical circuit, as with the first embodiment. An analog output display dial 485 or digital display screen with numeric values may also be employed. Reader is removably placed against the patient's skin to activate sensor 423 remotely located therefrom, and to obtain a pressure

measurement therefrom. Alternately, a removable adhesively bonded reader, like that shown as 201 in Figure 1, may be employed with *in vivo* sensor 423.

[0049] Reader 425 employs a secondary inductor integrated to an impedance analysis circuitry, where the phase of the readout coil shows a 'dip' nearby the resonant frequency of the sensor. Impedance measurements can use various methods such as a bridge method, resonant method, I-V method, RF I-V method, network analysis method and auto balancing bridge method. Preferably, an I-V method is employed for the reader electrical circuit. This method provides high accuracy and a wide impedance range at higher frequencies like 500 MHz. It applies an electrical current to a reference impedance in series with the readout coil and measures the voltage across the readout coil within a specific frequency range that covers the resonant frequency of the sensor. The coupling coefficient between the sensor and the readout coil is reflected to the readout impedance and measured by the module.

[0050] While various embodiments of the present sensor system have been disclosed, it should be appreciated that other variations may be made. For example, alternate electrical circuits and electronic components may be used although some of the present benefits may not be realized. Furthermore, different materials and manufacturing process steps can be used, however, certain of the present benefits may not be achieved. For example, the sensing coil assembly and protective layer may be entirely made from biodissolvable material such that the sensor does not need to be manually removed from the eye. The features of any of the embodiments may be mixed and matched in an interchangeable manner with any of the other embodiments disclosed herein. Various changes and modifications are not to be regarded as a departure from the spirit or the scope of the present invention.

CLAIMS

The invention claimed is:

1. An organ pressure sensing system comprising a sensor comprising a passive inductor having a stretchable undulating shape which is elongated to create at least a majority of a circle, and a polymeric protective layer encapsulating the inductor.
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2. The system of Claim 1, wherein the protective layer includes a circular outer edge.
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3. The system of Claim 2, wherein the protective layer includes a circular inner edge.
4. The system of Claim 1, further comprising only a single electronic component secured to the sensor.
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5. The system of Claim 4, wherein the component is a capacitor and the capacitor is part of a parallel resonance circuit.
6. The system of Claim 1, wherein the sensor is free of a microprocessor or battery, and the passive inductor is a variable inductor.
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7. The system of Claim 1, wherein the sensor is adapted for removable placement on a human eye and has an open center.
25
8. The system of Claim 1, wherein the sensor is adapted for placement on a cardiovascular organ.
9. The system of Claim 1, further comprising a reader including a reading coil, the reader being spaced away from the sensor and being spaced away from the organ.
30
10. An organ pressure sensing system comprising:

(a) an intraocular sensor including a passive metallic inductor within a polymeric carrier, the inductor having an elongated wavy shape with alternating curved peaks and valleys, and the wavy shape of the inductor surrounding an eye pupil centerpoint;

5 (b) a reader including a conductive coil, a microprocessor and a power supply; and

(c) the reader being spaced away from the sensor and the organ.

10 11. The system of Claim 10, further comprising only a single electronic component secured to the sensor.

12. The system of Claim 11, wherein the component is a capacitor and the capacitor is part of a parallel resonance circuit.

15 13. The system of Claim 10, wherein the carrier includes a circular outer edge and a circular inner edge.

20 14. The system Claim 10, wherein an eye-contacting surface of the carrier is parallel to an opposite outer surface of the carrier, and the carrier has a constant thickness along at least a majority of its length.

15. An intraocular pressure sensing system comprising a removable intraocular pressure sensor comprising:

25 (a) a deformable inductor having a substantially looped shape, the inductor being sized to contact an eye sclera surrounding outside a periphery of an eye cornea;

(b) a deformable outer ring spaced away from and surrounding the inductor, the outer ring being adapted to contact the eye sclera; and

30 (c) elongated connectors spaced apart from each other and spanning between the inductor and the outer ring.

16. The system of Claim 15, further comprising:
adhesive adhering the outer ring to the eye sclera;

the inductor having an undulating pattern along a majority of its length and being at least partially encapsulated within a polymeric layer; and

a capacitor coupled to the inductor being the only electronic component directly attached to the sensor.

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17. The system of Claim 15, further comprising a reader including a conductive coil, a microprocessor and a power-supply, the reader being spaced away from the sensor and the eye.

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18. A method of making a human organ pressure sensor, the method comprising:

(a) applying a coating of a first metal onto a substrate in a vapor deposition process;

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(b) applying a coating of a second and different metal onto the first coating in a vapor deposition process;

(c) creating an undulating shape to the metal coatings with a mask using photolithography;

(d) wet-etching the metal coatings after step (c), to create a variable inductor;

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(e) electrically connecting an electrical component, but not a microprocessor or battery, to at least one of the metal coatings;

(f) encapsulating the metal coatings inside a polymeric carrier; and

(g) the encapsulated inductor being capable of attachment to the organ and sensing pressure changes of the organ.

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19. The method of Claim 18, wherein the sensor is a passive intraocular pressure sensor capable of having a sensed signal read by a spaced apart active reader.

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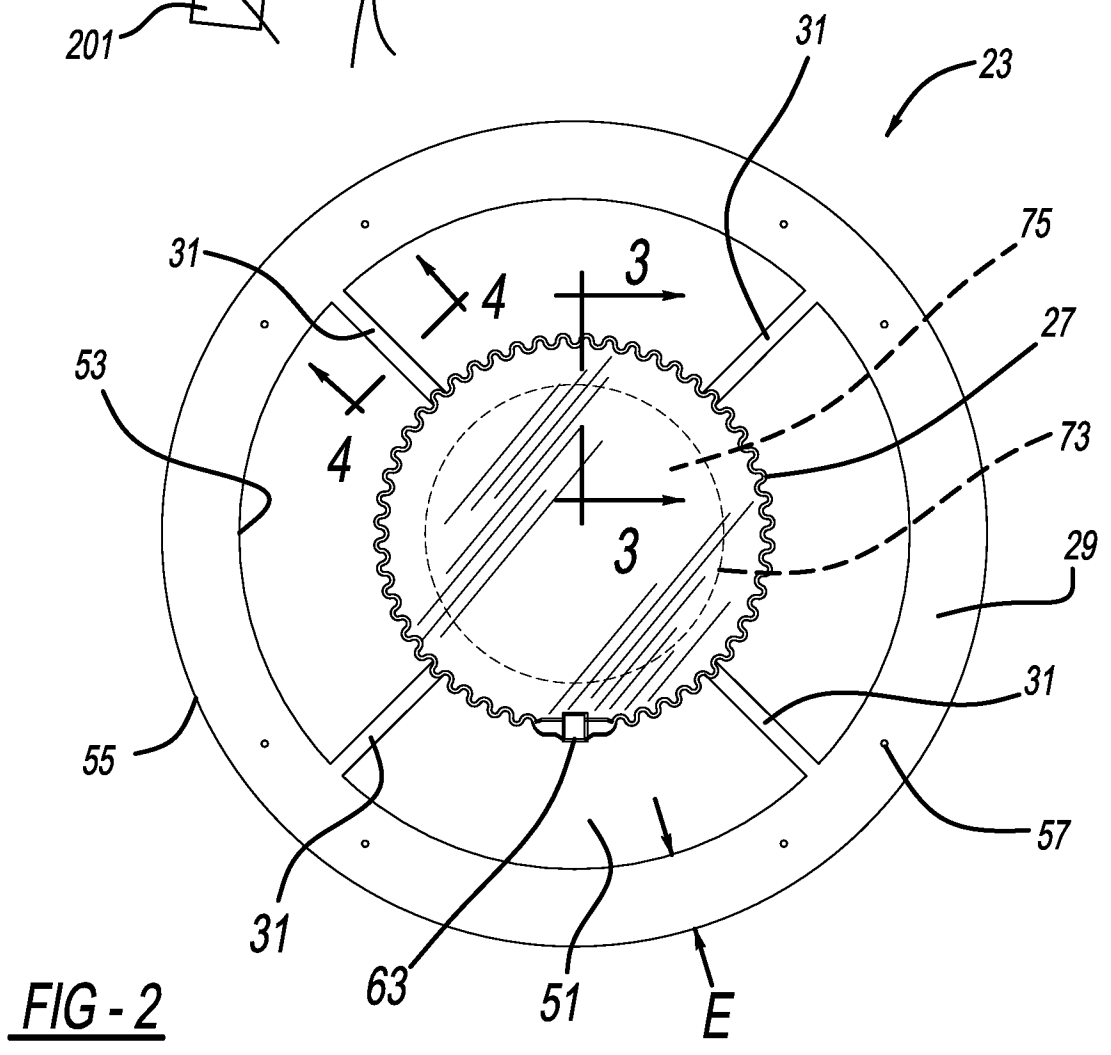
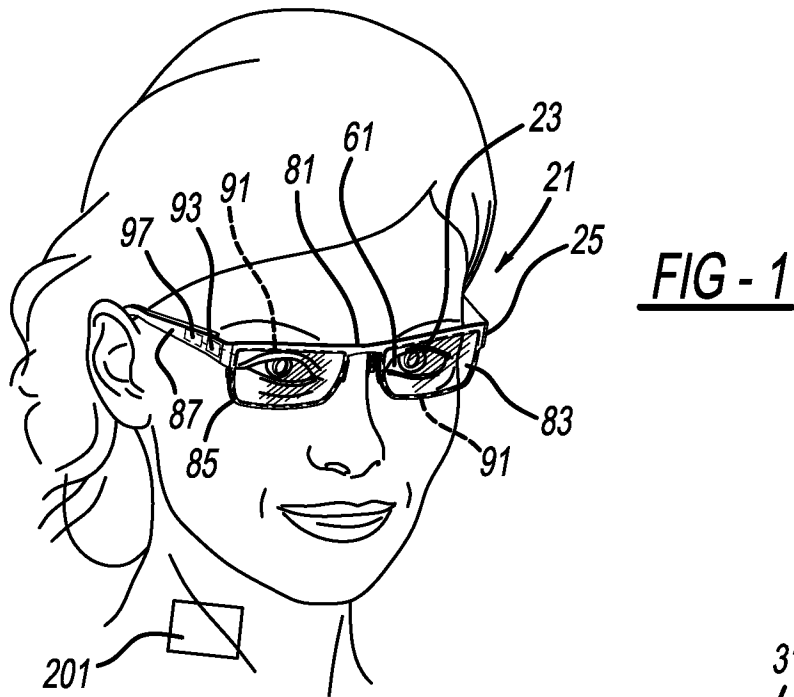
20. The method of Claim 18, wherein the sensor is a passive cardiovascular pressure sensor capable of having a sensed signal read by a spaced apart active reader.

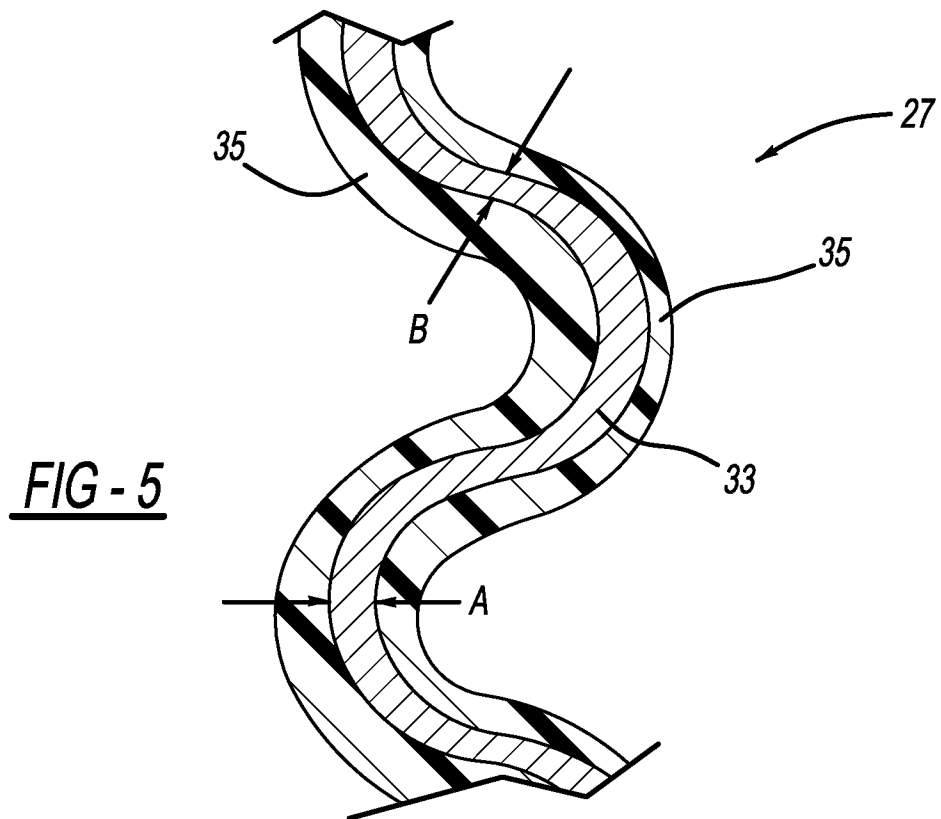
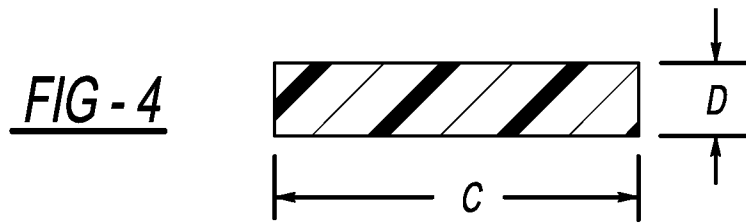
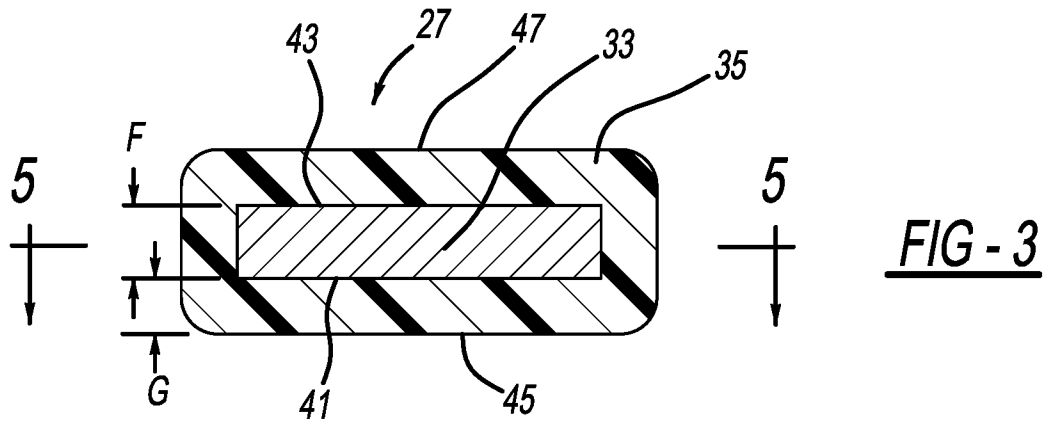
21. The method of Claim 18, further comprising three-dimensionally printing the encapsulating carrier.

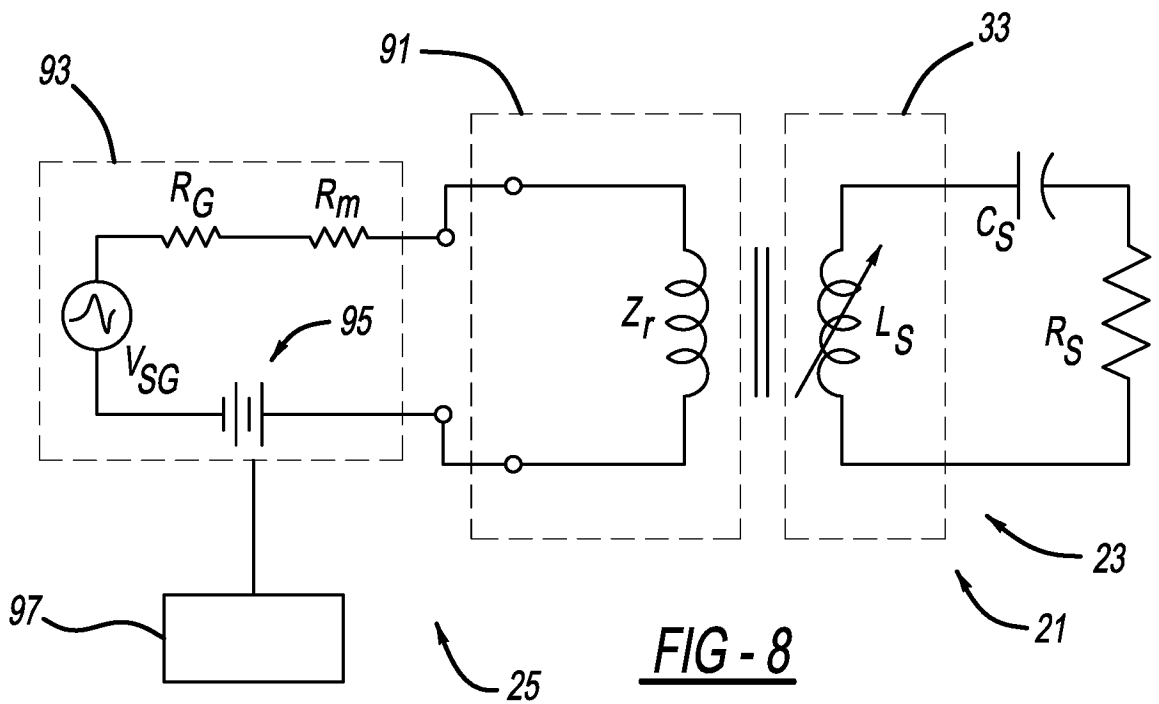
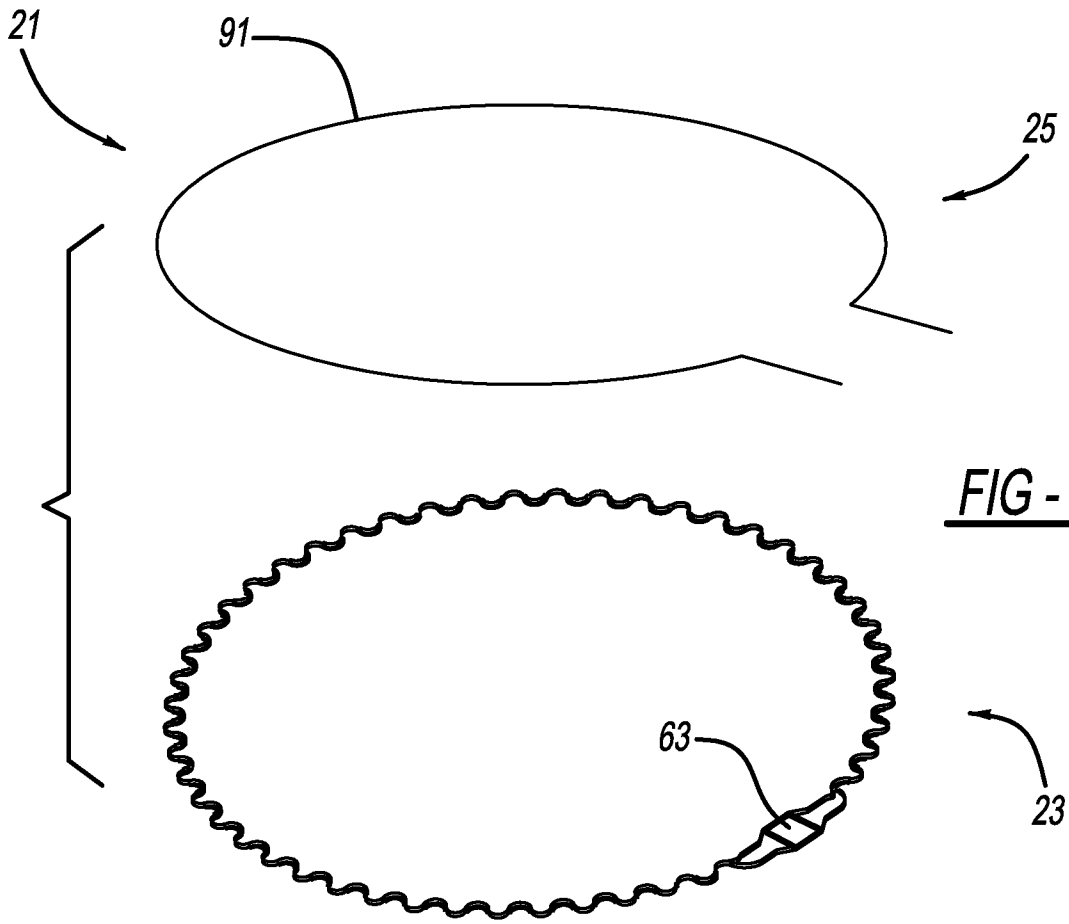
22. The method of Claim 18, further comprising molding the
5 encapsulating carrier into a shape matching an adjacent portion of an eye.

23. The method of Claim 18, further comprising using another photoresistant mask to protect the inductor during subsequent plasma dry etching of the carrier.

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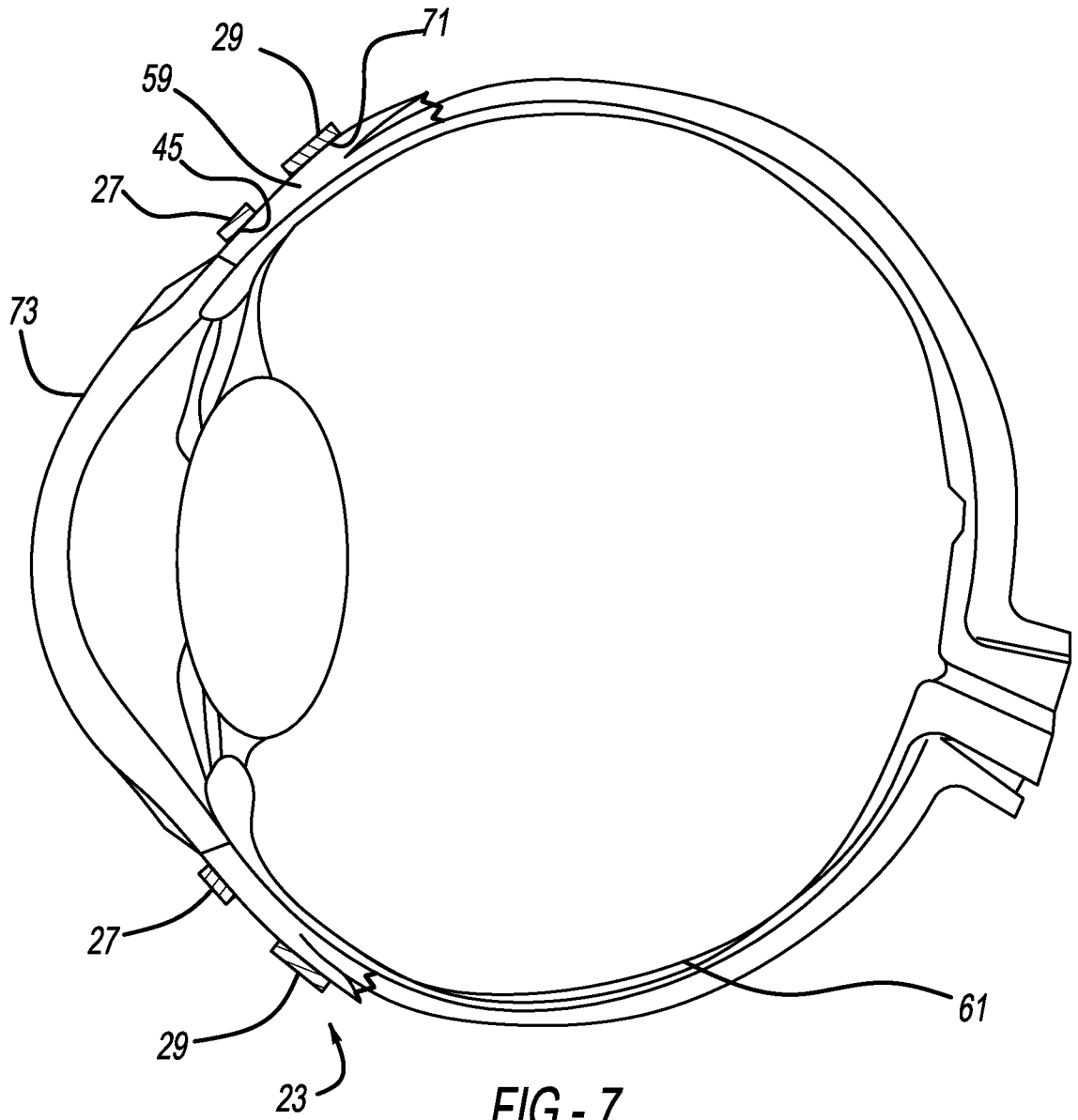


FIG - 7

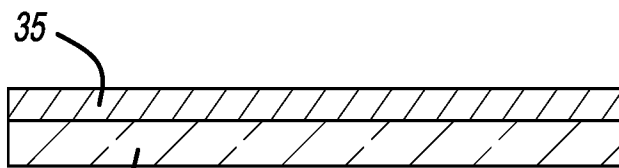
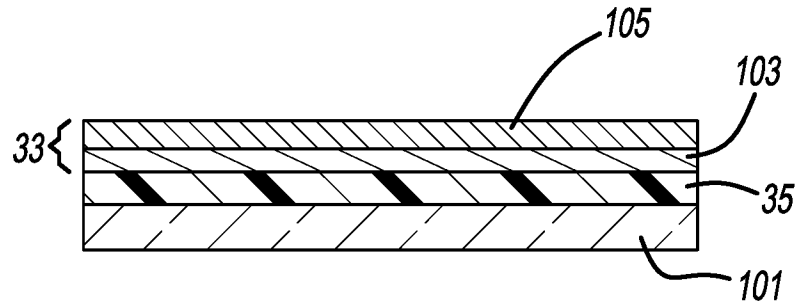
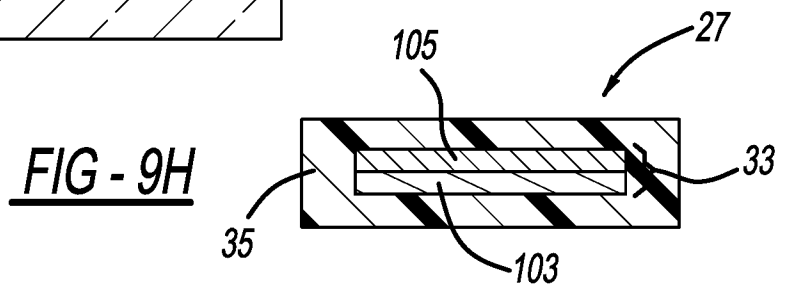
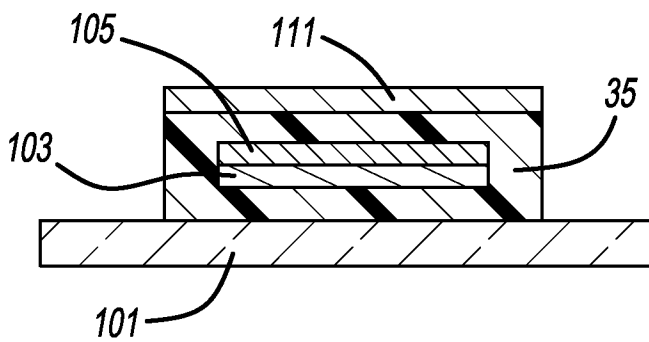
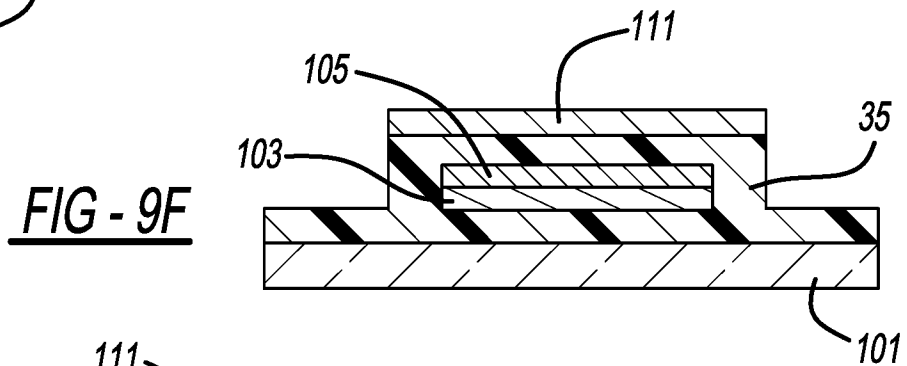
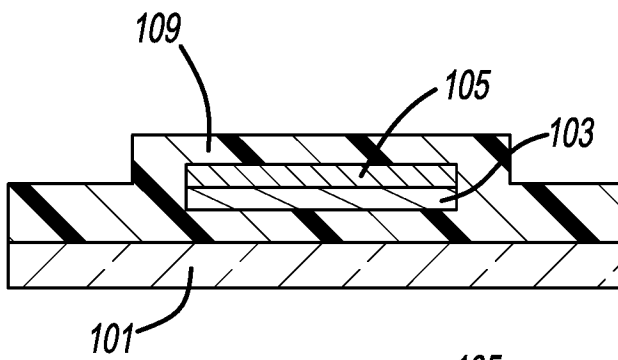
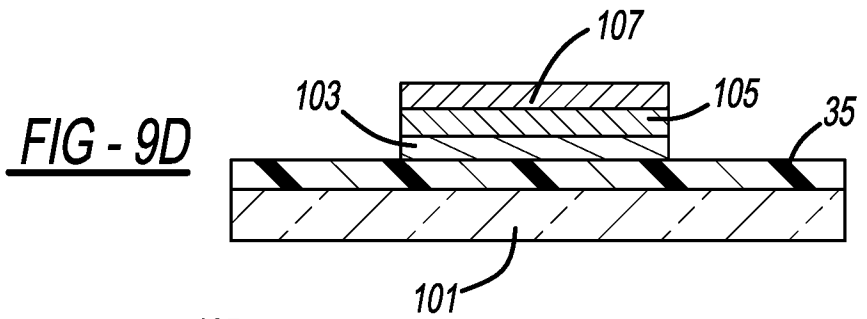
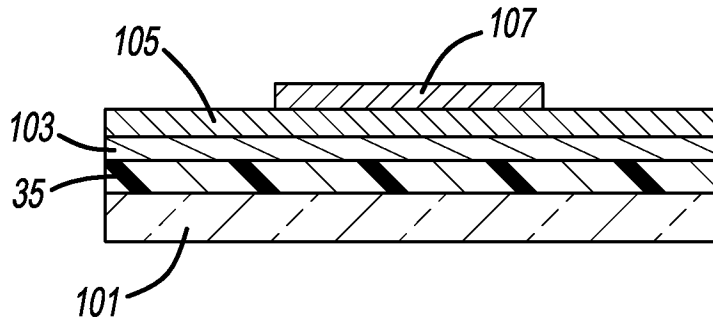


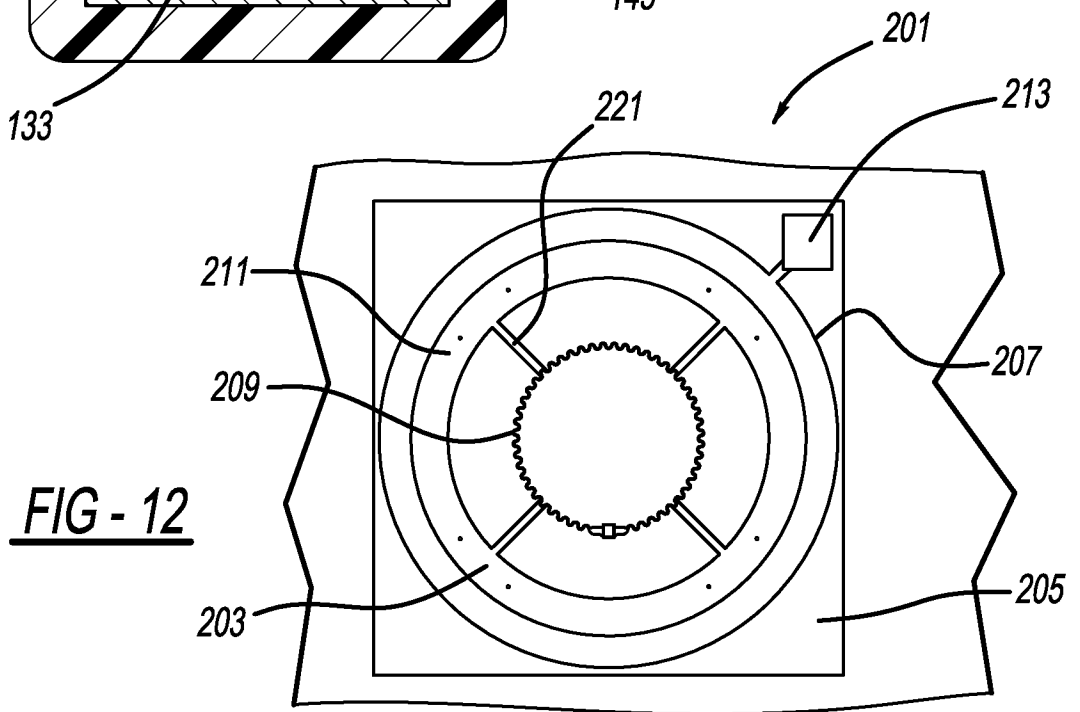
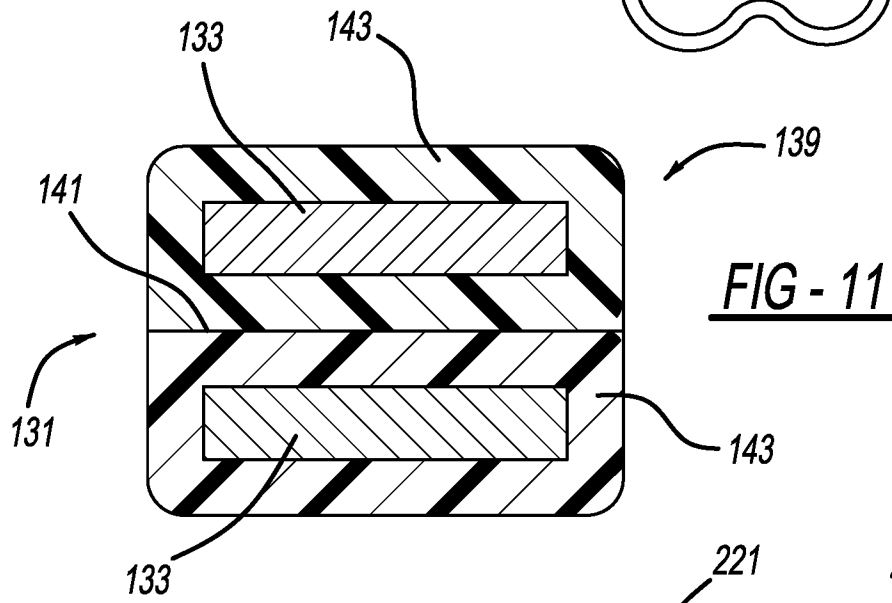
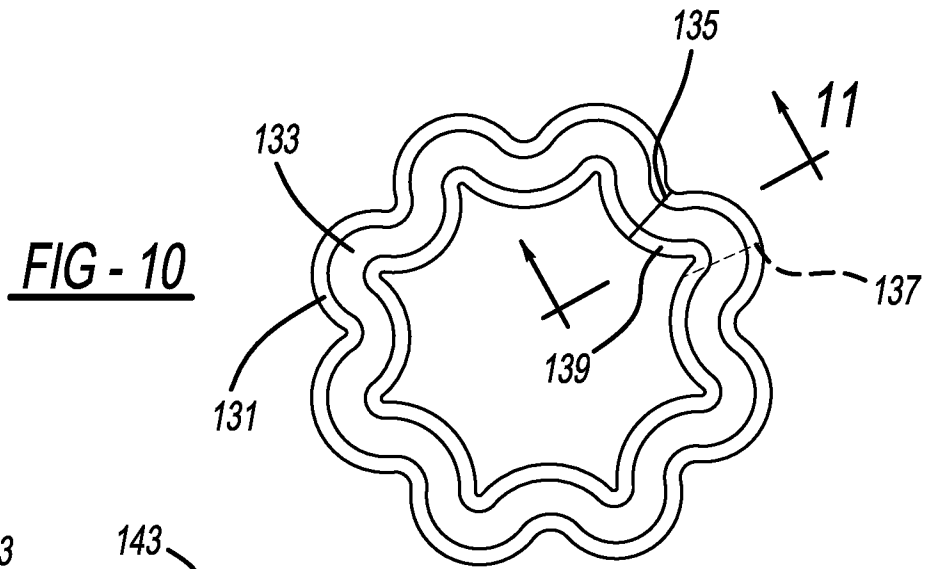
FIG - 9A

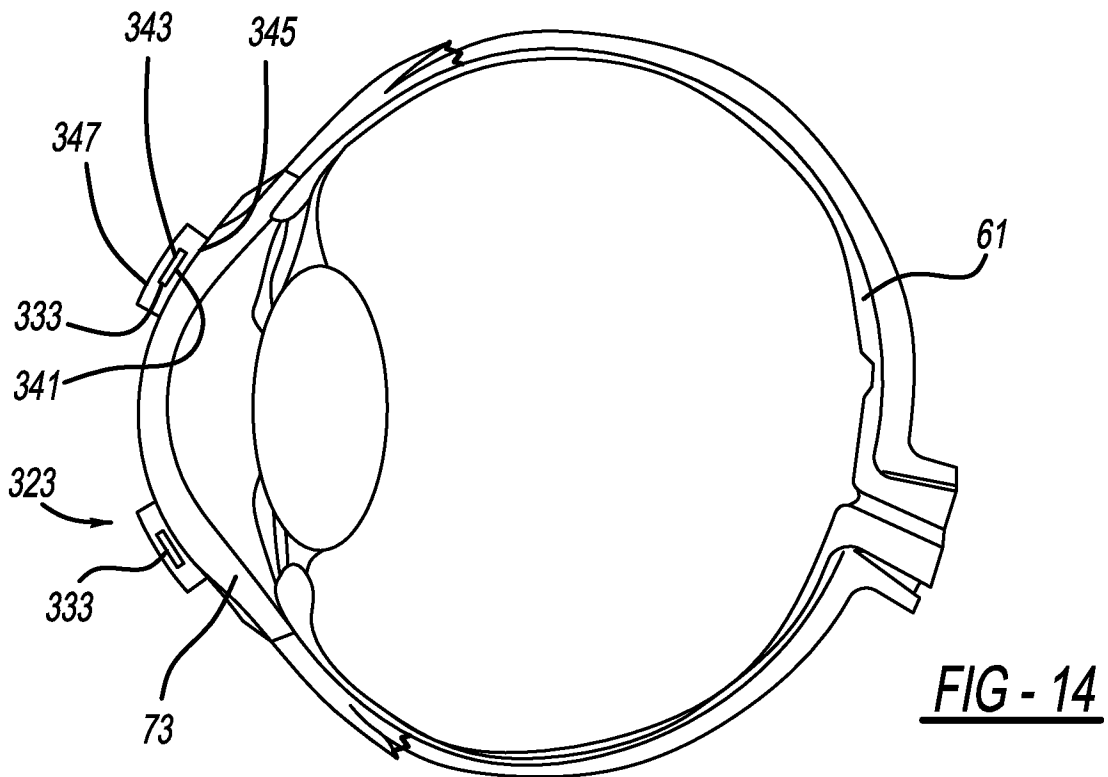
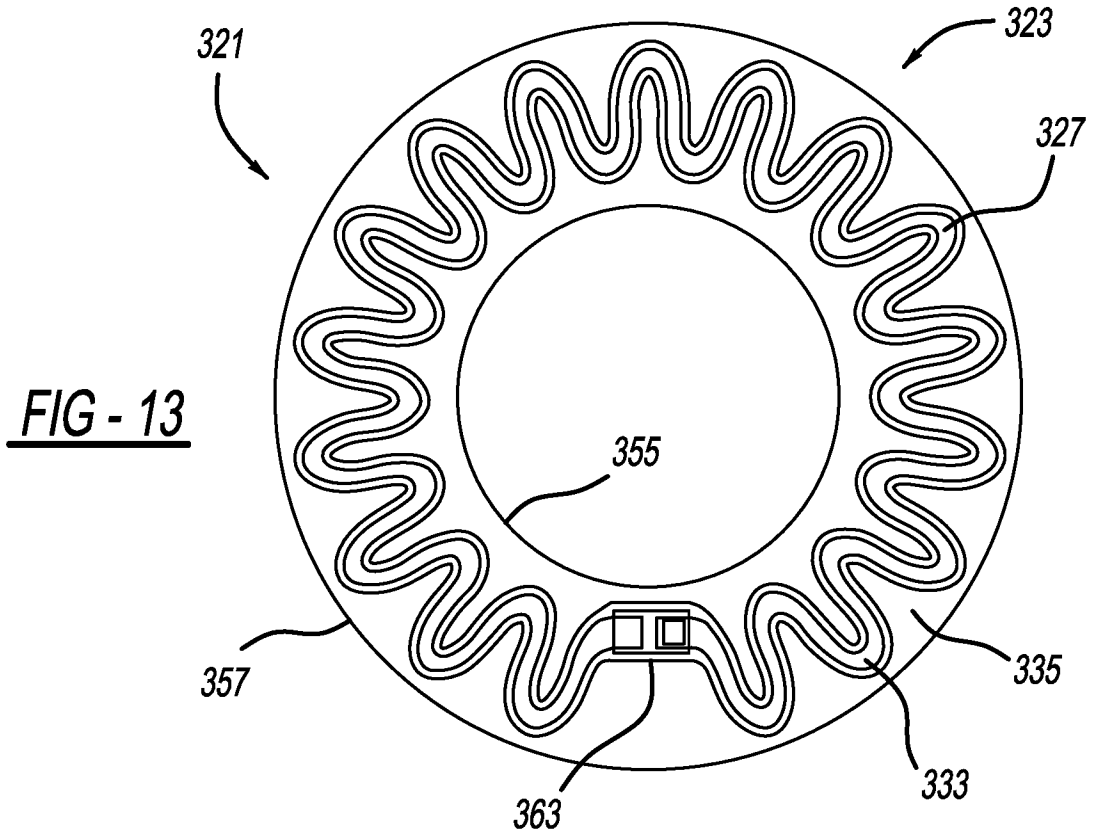
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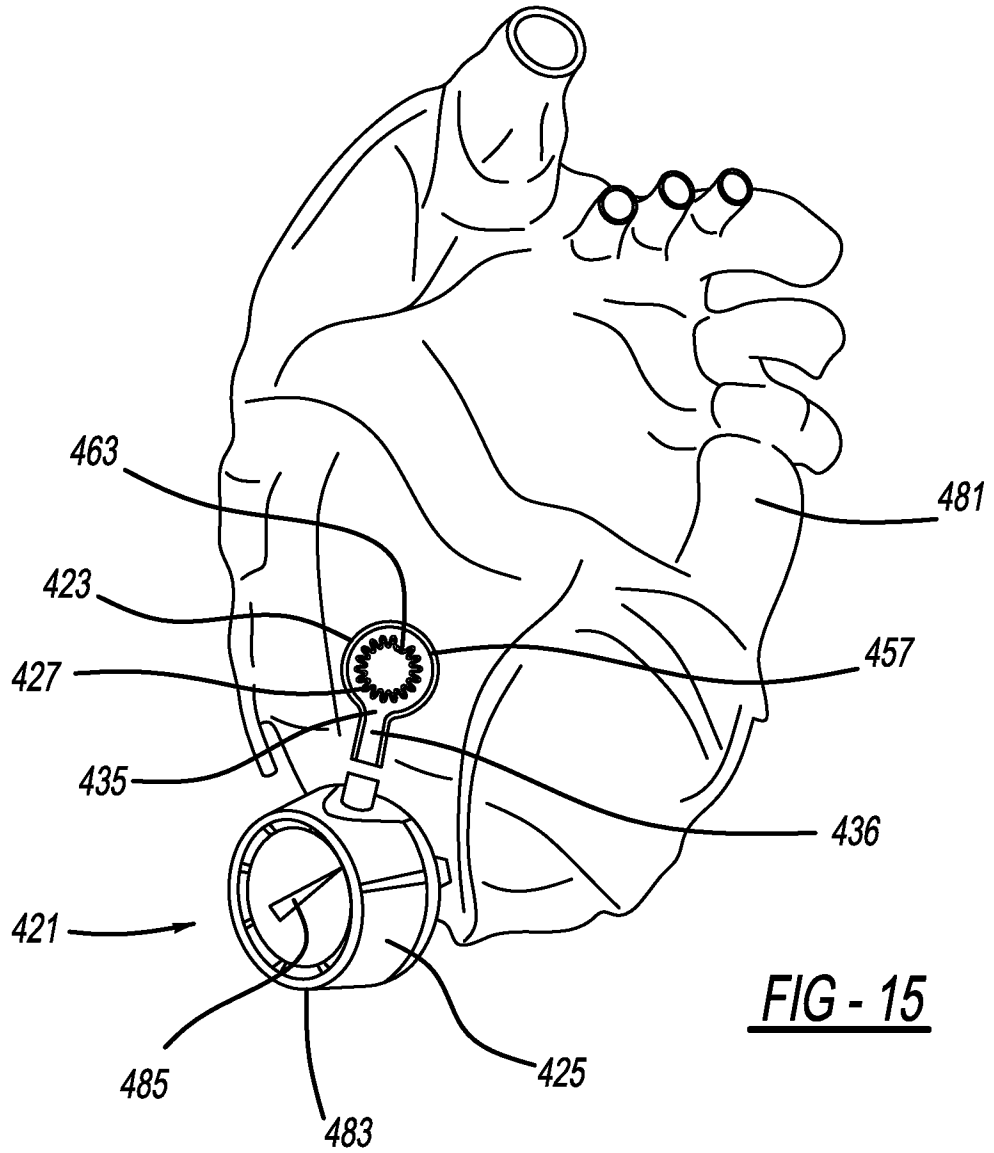
FIG - 9B











INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 18/23502

A. CLASSIFICATION OF SUBJECT MATTER
 IPC(8) - A61B 3/16, G01B 7/16, A61B 5/07, G02C 7/04 (2018.01)
 CPC - A61B 3/16, A61F 9/0008, A61F 9/0017, A61B 5/72, A61B 2562/028

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)

See Search History Document

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

See Search History Document

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

See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y -- A	M. H. M. Kouhani et al., "Wireless intraocular pressure sensor using stretchable variable inductor," 2017 IEEE 30th International Conference on Micro Electro Mechanical Systems (MEMS), Las Vegas, NV, 28 February 2017 (28.02.2017), pp. 557-560. Pg 557, para 7-8, pg 558, para 1 and 3, pg 560, para 1 and figs. 1-5 and 8. https://ieeexplore-ieee-org.turing.library.northwestern.edu/document/7863467/	1-14, 18-20, 22-23 ----- 21 ----- 15-17
Y	US 2015/0073253 A1 (SYNTEC TECHNOLOGIES, INC.) 12 March 2015 (12.03.2015) Entire document, especially para [0052]-[0053] and fig. 1A.	21
A	US 2016/0051143 A1 (CALIFORNIA BAPTIST UNIVERSITY) 25 February 2016 (25.02.2016) Entire document.	1-23
A	US 2013/0184554 A1 (ELSHEIKH et al.) 18 July 2013 (18.07.2013) Entire document.	1-23
A	US 2014/0243645 A1 (LEONARDI) 28 August 2014 (18.08.2014) Entire document.	1-23
A	US 2015/0087953 A1 (CHIOU et al.) 26 March 2015 (26.03.2015) Entire document.	1-23

Further documents are listed in the continuation of Box C.

See patent family annex.

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"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

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Date of the actual completion of the international search

08 May 2018

Date of mailing of the international search report

01 JUN 2018

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