

(43) International Publication Date  
30 September 2010 (30.09.2010)(10) International Publication Number  
**WO 2010/111225 A2**

## (51) International Patent Classification:

A61F 2/04 (2006.01) H04Q 9/00 (2006.01)  
A61M 39/22 (2006.01)

## (21) International Application Number:

PCT/US2010/028240

## (22) International Filing Date:

23 March 2010 (23.03.2010)

## (25) Filing Language:

English

## (26) Publication Language:

English

## (30) Priority Data:

61/162,614 23 March 2009 (23.03.2009) US

(71) Applicants (for all designated States except US): UT-BATTELLE, LLC [US/US]; One Bethel Valley Road, P.O. Box 2008, Oak Ridge, Tennessee 37831-8258 (US). BAYLOR COLLEGE OF MEDICINE [US/US]; One Baylor Plaza, BCM210-600D, Houston, Texas 77030 (US).

## (72) Inventors; and

(75) Inventors/Applicants (for US only): MCKNIGHT, Timothy E. [US/US]; 24070 Highway 95 N, Greenback, Tennessee 37742 (US). JOHNSON, Anthony [US/US]; 8810 Sager Dr., Houston, Texas 77030 (US). MOISE, Kenneth J., Jr. [US/US]; 5112 Patrick Henry Dr., Houston, Texas 77401 (US). ERICSON, M. Nance [US/US]; 612 Brochardt Blvd., Knoxville, Tennessee 37934 (US). BABA, Justin S. [US/US]; 833 Brochardt Blvd.,

Knoxville, Tennessee 37934 (US). WILGEN, John B. [US/US]; 108 Oklahoma Ave., Oak Ridge, Tennessee 37830 (US). EVANS, Boyd. M., III [US/US]; 949 W Outer Dr., Oak Ridge, Tennessee 37830 (US).

(74) Agent: GROLZ, Edward W.; Scully, Scott, Murphy &amp; Presser, 400 Garden City Plaza, Suite 300, Garden City, New York 11530 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

## (54) Title: REMOTE ACTUATED VALVE IMPLANT

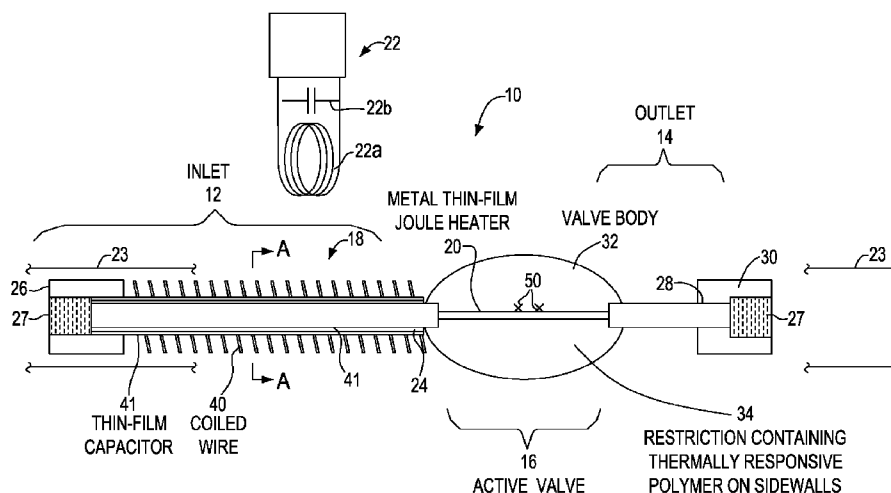


FIG. 1

(57) Abstract: Valve implant systems positionable within a flow passage, the systems having an inlet, an outlet, and a remotely activatable valve between the inlet and outlet, with the valves being operable to provide intermittent occlusion of the flow path. A remote field is applied to provide thermal or magnetic activation of the valves.



---

**Published:**

- *without international search report and to be republished  
upon receipt of that report (Rule 48.2(g))*

## REMOTE ACTUATED VALVE IMPLANT

### FIELD OF THE INVENTION

**[0001]** The present disclosure relates to the field of implantable medical devices. More particularly, the disclosure relates to a system that enables a valve to be inserted within the body and remotely activated for controlling the flow of fluid in physiological channels.

### BACKGROUND OF THE INVENTION

**[0002]** A medical condition known as congenital diaphragmatic hernia (CDH) is a potentially fatal congenital birth defect in fetuses characterized by abnormal development of the diaphragm which causes herniation of abdominal organs in the chest, resulting in decreased lung development in the fetus. CDH is one of the leading causes of in-hospital neonatal death.

**[0003]** One technique used to treat CDH is a balloon tracheal occlusion procedure such as described in JOURNAL OF PEDIATRIC SURGERY, Vol. 38, No. 7 (July 2003) at pp. 1012-1020. In accordance with the balloon tracheal occlusion (TO) procedure, under direct visualization, a detachable balloon is positioned just above the

fetal carina and inflated with an isotonic solution to provide an occlusion or obstruction. The inflated balloon is left in place until either the fetus is delivered or a removal procedure is performed when the fetus is approximately 34 weeks of age. While the TO procedure has provided some benefits, various disadvantages are believed to be associated with the procedure.

## **SUMMARY OF THE INVENTION**

**[0006]** The disclosure relates to a valve implant system positionable within a flow passage, the system comprising an inlet, an outlet, and a thermally activatable valve between the inlet and outlet. The system may be located in a flow path and used to provide intermittent occlusion of the flow path.

**[0007]** The valve may be provided by a tubing or other conduit having therein a polymer that changes phase upon application of heat. The phase-change of the polymer results in the polymer occluding flow through the valve. At ambient temperature (e.g. body temperature) the polymer expands and blocks flow. When heated, the polymer changes phase, shrinks, and permits flow. The polymer may also be engineered to reverse the temperature control characteristics. That is, to have the valve in an open state under ambient conditions and to occlude flow through the valve when heated.

**[0008]** The valve system may be located in a flow path and used to provide intermittent occlusion of the flow path. For example, the system may be used to treat CDH by using the valve system to intermittently occlude the fetal trachea. However, the system is suitable for additional uses within the body for controlling fluid flow.

**[0009]** In accordance with a particular embodiment, a valve implant system is configured for being disposed within a flow passage and includes a left end tube connected to a left intermediate tube, which in turn is connected to a balloon having a diameter sized to be positioned within and blocking a flow passage. A valve tube is disposed in the balloon and is connected to the left intermediate tube, and a polymer is disposed in the valve tube. The polymer is selected to expand at ambient temperature and shrink when heated above ambient temperature, and the polymer is configured and

disposed for blocking the passageway of the valve tube at ambient temperatures and for shrinking when the polymer is heated to open the passageway in the valve tube.

**[0010]** A heater is disposed proximate the polymer for heating the polymer; and a power supply provides power to the heater to cause the heater to heat the polymer and open the passageway in the valve tube. One end of a right intermediate tube is connected to the balloon and the valve tube at the second end of the valve tube; and a right end tube is disposed on the other end of the right intermediate tube. In this configuration, when the polymer is heated, an open composite passageway is formed through the left and right end tubes, the left and right intermediate tubes and the valve. When the polymer is unheated and attains ambient temperature the polymer expands and the composite passageway is blocked by the polymer.

**[0011]** Herein the terms “left” and “right” or “first” and “second” are used as proper names to help distinguish one part from another, but no position information is intended. In other words, a right structure or thing may be positioned anywhere, including on the left, and a first structure or thing is not ordered in any sense with respect to a second structure or thing.

**[0012]** The system may also include side ports formed in the sides of the left and right intermediate tubes for allowing fluid flow between the passageways and the exteriors of the left and right intermediate tubes. Also, a MEMS diaphragm pressure transducer may be mounted to sense the pressure in the composite passageway, and a communication link may be provided for transmitting information corresponding to the pressure sensed by the pressure transducer. The pressure measurements may be used in conjunction with valve parameters to compute flow rates as a type of flow sensor. Other flow sensors including thermal mass flow meters or “hot-wire” anemometers may be used in conjunction with this device. Likewise temperature sensors may be mounted to sense the temperature of the heater or polymer, and a communication link may transmit information corresponding to the temperature sensed by the temperature transducer. The system may also include a power transmitter, such as an RF transmitter, for transmitting power to the power source, and the power source may be a receiver of electromagnetic energy, such as a coil. 12.

**[0013]** In yet further embodiments, electromagnetic valves are provided which include an energy receiving coil and an actuation coil. The valves are normally in a “closed” state to restrict fluid from traveling from the inlet through the valve and out the outlet. The valves are placed in an “open” state by applying an external electrical field to the energy receiving coil to activate the actuation coil to place the valve in an “open” state. The valves may be configured to return to a “closed” state upon removal of the field, or to remain “open” if desired.

**[0014]** In further embodiments, means are provided for locking the electromagnetic valve open to allow for the procedure to be discontinued at the desired lung growth and as a means to open air passageways post delivery.

**[0015]** Further means are provided for remotely “deflating” the balloon which positions the occlusion device in the trachea in which case it would be naturally expired prior to birth negating the need for a removal procedure. Means for deflating the balloon include using the thermally activated polymer as a means to seal the balloon itself. Alternately, this could be accomplished with an electromagnetic valve configuration. The remote valve deflation using thermally sensitive polymers may be incorporated with remote fluid control valve using resonant circuits that are tuned to different frequencies.

**[0016]** In another embodiment, a thermally activated valve having an internalized heating element and a thermally responsive polymer grafted thereon is provided. The thermally activated valve also has an outer bore tubing within which the internalized heating element and thermally responsive polymer is arranged.

**[0017]** In another embodiment, a thermally actuated valve having a valve element including a thermally responsive polymer and a solid element attached to the thermally responsive polymer is provided. The valve element switches between at least two configurations to adjust the flow rate of fluid through a valve seat.

**[0018]** In another embodiment, a thermally actuated valve is provided with a copolymer formulation allowing the valve to be in either a normally closed state or a normally open state.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0019] Further advantages of the invention are apparent by reference to the detailed description when considered in conjunction with the figures, which are not to scale so as to more clearly show the details, wherein like reference numbers indicate like elements throughout the several views, and wherein:

[0020] FIG. 1 shows a remote actuated valve implant system according to one embodiment of the disclosure configured for use in treating CDH, and FIG. 1A is a cross-sectional view taken along line A-A of FIG. 1.

[0021] FIGS. 2A and 2B show polymer within tubing as utilized in the system of FIG. 1.

[0022] FIG. 3 shows a system for producing thermally-responsive beads for use in the system of FIG. 1.

[0023] FIG. 4 shows an alternate embodiment of a heater for use with the system of FIG. 1.

[0024] FIGS. 5A and 5B show an alternate embodiment of the system of FIG. 1, in which the polymer is contained within expandable lumens.

[0025] FIGS. 6A and 6B show further embodiments of valve systems incorporating an inductive pickup coil having a ferrite core.

[0026] FIG. 7 shows an alternate embodiment of a remote valve implant system configured for use in studying pressure effects of lung development.

[0027] FIGS. 8A and 8B show an alternate embodiment of an implant valve system having an electromagnetic valve.

[0028] FIGS. 9A and 9B show an inflation device that may be utilized with the systems disclosed herein for inflating a balloon component of the systems.

[0029] FIGS. 10A-10C show a further embodiment of an implant valve system having a latch mechanism that enables the valve to remain open.

[0030] FIGS. 11A and 11B show yet another embodiment of an implant valve system having a combined coil that provides both energy reception and valve actuation functions.

[0031] FIGS. 12 and 13 show additional embodiments which facilitate remote deflation of a balloon.

[0032] FIG. 14 shows an alternate embodiment of a valve system that utilizes a thermally responsive polymer.

[0033] FIG. 15 shows an external electrical power source for the system configured to operate in parallel resonance mode.

[0034] FIG. 16 shows an external electrical power source for the system configured to operate in series resonance mode.

[0035] FIGS. 17 and 18 show another embodiment of an implant valve system having an internalized heating element with a thermally responsive polymer grafted thereon.

[0036] FIG. 19 shows another embodiment of an implant valve system having a valve element including a thermally responsive polymer and a solid element attached thereon.

## DETAILED DESCRIPTION

[0037] Referring to FIGS. 1, 1A, 2A, and 2B, one embodiment of a remote actuated valve implant system **10** is shown. The system **10** may be used in medical procedures involving the control of fluid flow in physiological channels. The system **10** may be used to treat medical conditions such as CDH, hydrocephalus, urinary incontinence, diabetes, gall bladder disease, and diseases of the reproductive system.

[0038] As illustrated in FIG. 1, the system **10** includes an inlet **12**, an outlet **14**, a thermally activatable valve **16**, an electrical circuit provided by a pickup coil **18** electrically coupled to a heater **20**, and an external electrical power source **22**.

[0039] A basic operation of valve **16** is illustrated in FIGS. 2A and 2B. The valve **16** is normally in a “closed” state to restrict fluid from traveling from the inlet **12** through the valve **16** and out the outlet **14**. The valve **16** is placed in an “open” state by applying an external field with the power source **22** to the pickup coil **18** to power the heater **20** to heat and thereby activate the valve **16** to the “open” state. As used herein “field” is used broadly to include an electric field, magnetic field or electromagnetic wave. Upon removal of the field of power source **22**, the valve **16** will return to the “closed” state. Thus, the system **10** may be located in a flow path **23** and used to provide intermittent occlusion of the flow path **23**.

[0040] As an example, the system **10** described herein is configured for use in treating CDH. In this regard, the inlet **12** may be provided by tubing **24**, such as 800 micron o.d., 300 micron i.d. medical grade tubing, such as polyimide-coated, fused-silica capillary tubing. The free end of the tubing **24** can include a section of 1-mm o.d., 800 micron o.d. silicone tubing **26**. The tubing **26** may be useful to reduce the potential of tissue interactions at the possibly sharp, cleaved end of the tubing **24**. In addition, or in the alternative, a screen or filter material **27** may be provided to filter any undesirably large particles.

[0041] The outlet **14** can be substantially identical to the inlet **12**, and includes tubing **28**, made of the same material as the tubing **24**. The free end of the tubing **28** can include a section of 1-mm o.d., 800 micron i.d. silicone tubing **30** or the filter **27** or both.

[0042] The thermally activatable valve **16** includes a valve body **32** surrounding a section of tubing **34** and enclosing a thermally responsive polymer **36**. The polymer **36** is expanded under ambient body conditions (e.g. body temperature) and effectively restricts fluid flow through the tubing **34**. Thermal activation of the polymer **36** shrinks or reduces the volume of the polymer **36** so as to enable fluid to flow through the tubing **34**, and in one embodiment the polymer may shrink to 50% of its original volume.

[0043] The valve body **32** functions to immobilize the valve **16** within the desired fluid passageway **23**, such as the fetal trachea, and also functions to thermally insulate the thermally responsive polymer **36** within the tubing **34** from surrounding body

tissue. In this regard, further insulation may be provided by providing a secondary layer of insulating material or by filling the valve body with a gas or other insulating material. As described herein, in one embodiment, the valve body **32** may be provided as by a pediatric inflatable balloon of the type used in a tracheal occlusion procedure. However, it will be understood that other structures effective to immobilize the valve **16** within the fluid passageway **23** may be used.

[0044] The ends of the tubing **34** are connected to the tubing **24** and **28** of the inlet **12** and outlet **14**, respectively. The tubing **34** is smaller than the tubing **24** and **28** of the inlet **12** and outlet **14**, and can, for example, be 300 micron o.d., 75-150 micron i.d. medical grade tubing, such as polyimide-coated, fused-silica capillary tubing.

[0045] The thermally responsive polymer **36** is prepared so as to exist in a swollen state at normal body temperature (e.g.  $\sim 37-39^{\circ}\text{C}$ ), and to collapse at an elevated temperature close to but above normal body temperature (e.g.  $\sim 40-41^{\circ}\text{C}$ ). For the polymer **36** to be suitably thermally responsive, the polymer **36** preferably has a lower critical solution temperature (LCST) slightly above physiological temperature, such as  $40-41^{\circ}\text{C}$ , so that the polymer undergoes a phase change at the LCST temperature. In this regard, the terminology “phase” or “phase change” as used herein refers to changes in the molecule shape and swelling, including changes in the hydrophobic or hydrophilic characteristics. For example, the phase change of the polymer **36** in the tubing **34** causes the polymer to contract and renders the valve **16** in an open state enabling fluid to flow through the tubing **34**.

[0046] The polymer **36** is preferably provided within the tubing **34**, such as by covalent attachment of either discrete spheroids of the polymer (packed bed), or by in-situ polymerization of the polymer using conventional acrylamide to silica adhesion techniques (continuous monolith).

[0047] For example, with reference to FIGS. 2A and 2B, there is shown the polymer **36** within the tubing **34**, with the tubing **34** being provided by a single channel of 150 micron o.d., 75 micron i.d. fused silica. The internal wall of tubing **34** is coated using 3-methacryloxypropyltrimethoxysilane (MAPTOS) to bind polyacrylamide based

hydrogel during radical polymerization. This molecule will chemically bind or anchor the polymer on the internal wall of the tubing **34**. Exemplary polymers include, but are not limited to, a polymer such as pNIPAM copolymered with N,N-dimethylacrylamide (DMAA) or other suitable copolymer material adjusted to provide an LCST of 40 °C or more. At body temperature, the polymer **36** will exist as a hydrogel and spatially occlude the flowpath **23**, as seen in FIG. 2A, generating backpressure. At temperatures above the LCST, as will occur upon application of the external electrical field of power source **22**, the polymer **36** will collapse against the sidewall (monolith), as seen in FIG. 2B, and allow fluid flow. Backpressure is dependent on monolith porosity and polymer filling monolith voids. Utilizing parallel paths of smaller diameter will provide higher backpressures when the valve is closed at body temperature. In this regard, multiple parallel capillaries may be used instead of a single tubing element. However, such multiple parallel capillaries will be smaller diameter capillaries, and a filter (such as the filter **27**) can be incorporated to filter particles larger than the internal diameter of the entry/exit regions.

**[0048]** The polymer **36** may preferably be a hydrogel, such as optimized poly-n-isopropylacrylamide-polyacrylic-acid p(NIPAAm) copolymers, p(NIPAm)-co-DMAA. The monodispersed microgels of P(NIPAAm) and related thermally responsive polymers may be generated using redox initiated polymerization in monodisperse aqueous-in-paraffin emulsion on a microfluidic channel. Generation of microgels using redox initiated polymerization advantageously enables rapid determination and optimization of the LCST and of the swelling volumes of various polymers via evaluation of bead diameter in artificial amniotic fluid with optical microscopy on a heated stage, such as illustrated in FIG. 3, which shows ~20 micron alginate microgels **37**. Preferably, when the polymer **36** is heated, it shrinks and provides a passageway having a diameter of about 30 to 100 microns in the tubing **34**. The open passageway will typically have an irregular shape and a circuitous path, and reference to a diameter of such irregular passageway refers to a diameter in a round tube that would provide the same flow as the irregular passageway. Such diameter may be considered an effective diameter.

[0049] As illustrated in FIG. 1A, the pickup coil **18** may be provided, for example, by wrapping a coil wire **40** around the tubing **24**, or the tubing **28**, or both. The coil **18** may be configured to operate in either series or parallel resonance mode by the addition of a capacitor. The wire **40** may be 50+ gauge wire suitable for making a magnet. The wrapped wire **40** constructs the coil **18** which may be excited by application of the external field of power source **22** which may be provided by an external coil **22a** or an electrical transmitter such as a radio transmitter. The wire **40** is electrically connected to the heater **20** such that when the external electrical field of source **22** is brought in proximity to the wire **40**, a current is induced in the wire **40** to power the heater **20**.

[0050] The power source **22** may be provided as by an externally located drive coil **22a** capable of generating a sufficient field to induce a desired voltage on the pickup coil **18** sufficient to provide the desired power to the heater **20**. The power source **22** may also incorporate a capacitor **22b** to operate in series or parallel resonance mode thus improving efficiency of oscillation and frequency selectivity. For example, 60  $\mu$ W of thermal power for a period of about 60 seconds may be achieved by energizing a coil made of 52 gauge wire having about 200 turns with 1 mm o.d. using an RF field centered in one of the Industrial, Scientific, and Medical (ISM) bands (6.78MHz, 13.56 MHz, 27.12 MHz, or 40.68 MHz) or other suitable band.

[0051] A flexible-film capacitor **41** which can conform to the hollow, tubular geometry may be included with the wire **40** to tune the resonance of the circuit provided by the pickup coil **18**. That is, the wire **40**, capacitor **41**, and the resistance of the heater **20** are selected to resonate with the inductive drive coil **22a** and capacitor **22b**. The capacitor **41** may also be constructed using other conventional methods. In addition, ultrasound imaging may be used to facilitate alignment of the power source **22** with the pickup coil **18**. Alternatively, the power source **22** may be provided partly or in whole by use of an implanted battery as opposed to being remote.

[0052] The heater **20** may in one embodiment be provided as by patterning the tubing **34** with a physical vapor deposited thin-film metal resistance heater using shadow masking with laser machined polyimide-based adhesive templates. In another

embodiment, shown in FIG. 4 installed within a fetal trachea, a resistive wire **25** may be wrapped around the tubing **34** to provide the heater **20**. The heater **20** is operable to heat the polymer **36** within the tubing **34** up to the desired temperature to accomplish phase change. To avoid overheating, the heater **20** is configured so as to not raise the temperature of the polymer **36** more than about 5 °C. The exterior of the overall assembly of the inlet **12**, outlet **14**, valve **16**, and heater **20** is preferably passivated or insulated by a conformal coating of a passivating or insulating material, such as Parylene-C.

[0053] Modified examples of the above-described system 10 is provided below.

[0054] In a first modification, conductive materials may be placed within, around, and/or enmeshed in the polymer **36**. Passage of DC or AC current through the conductive materials release heat, thereby raising the temperature of the conductive materials and the polymer **36**. The valve **16** is thereby actuated by Joule heating.

[0055] In a second modification, valve **16** can be actuated by induction heating. Conductive material may be placed in thermal contact with the polymer **36**. The conductive material is heated by electromagnetic induction, where eddy currents are generated within the conductive material and resistance leads to Joule heating of the conductive material.

[0056] The conductive material may be a continuous conductive material internal or external to the polymer **36**, or the conductive material may be discontinuous conductive materials embedded within or around the polymer **36** such as discrete nano- and microspheres of metals or metallic conductors.

[0057] Magnetic materials may be incorporated within, around, or enmeshed in the polymer **36** to provide heating via induction heating. These magnetic materials may include nano- and microparticles of magnetic materials which are heated by inductive heating. These magnetic materials may include Curie thermoregulated materials such that heating can be controlled by the transition of these magnetic materials from ferro/feri magnetic below the Curie point to paramagnetic above the Curie temperature.

[0058] In a third modification, the valve 16 can be actuated by ultrasonic excitation. Ultrasonic energy is focused on or around the valve 16 to generate heat in the tissue surrounding, or the materials including and surrounding the valve 16.

[0059] As an example, enhanced heating can be achieved by arranging ultrasound contrast agents around the polymer 36 such that the absorption of ultrasonic energy is enhanced in the region surrounding the polymer 36.

[0060] In a fourth modification, the valve 16 can be actuated by infrared or near-infrared heating. In particular, near-infrared heating may be beneficial due to the significant tissue penetration depth of near infrared at wavelengths within a therapeutic window of 700-1200 nm.

[0061] As an example of near-infrared heating, gold nanospheres are incorporated into the polymer 36. These gold nanospheres may then be heated by near infrared energy, including multiphoton excitation of multiple convergent rays of near infrared radiation.

[0062] In a fifth modification, the valve 16 can be actuated by physiological situations. Examples of physiological situations that can be harnessed to actuate valve 16 include, but are not limited to, elevated body temperatures due to fever, infection, microbial process, increased activity/metabolism of cells and tissue including exercise and physical exertion, and increased growth/proliferation/metabolism of cells, including tumor cells.

[0063] In a sixth modification, the valve 16 can be actuated by convective or conductive heating of the tissue surrounding the valve 16.

[0064] An insulating layer may also be provided around the heater 20 to reduce energy requirements. An example of an insulating layer 49 arranged around the heater is shown in FIG. 13. The system 10 may also utilize a thermostat system in conjunction with the heater 20 to inhibit temperature increases of the system 10 beyond desired operation levels. For example, the system 10 may also include a cut-off switch, such as may be provided by a bi-metallic strip of material which will terminate power to the heater 20 at a desired temperature. Alternatively, thermocouples 50 or thermistors or the

like may be located on the tubing 34 to measure the temperature and incorporate that measurement into an algorithm for supplying power to the heater 20 to control temperature. Furthermore, integrated pressure measuring devices may be used with implanted signal processing to fully automate control of the valve 16, enabling optimized pressure-based valve control.

[0065] In use, an assembly having the inlet 12, outlet 14, valve 16, coil 18, and heater 20 is desirably located in a physiological channel of the body, such as a fetal trachea as shown in FIG 4. As desired, the power source 22 may be utilized to place the valve 16 in a closed state as described to control the flow of fluid through the valve, and hence the physiological channel of the body. Thus, in the case of treating CDH, the fetal trachea may be intermittently occluded, versus continuously occluded as occurs with conventional TO techniques. It is believed that treatment advantages may be achieved by providing intermittent occlusion.

[0066] With reference to FIGS. 5A and 5B, there is shown a further embodiment of a system 10' that may be identical to the system 10, except the polymer 36 is contained within expandable lumens 51 within the tubing 34. The lumens 51 are adjacent the sidewall of the tubing 34 such that when the valve is in the normal closed state (FIG. 5A), the swollen polymer expands the lumens 51 to occlude the tubing 34. The lumen provides an elastic capability to allow for expansion and contraction of the polymer. The expandable lumen incorporates a means for allowing water to be expelled or absorbed into this system such as a membrane, perforation, or other method. When the external field of source 22 is supplied and the polymer 36 within the lumens 51 is heated, the polymer shrinks and the lumens 51 deflate to open a flow path, as seen in FIG. 5B.

[0067] In another embodiment, shown in FIG. 6a, an inductive pickup coil 52 having a ferrite core 54 may be used to provide the coil 18. Such coil/core may be located at the inlet, outlet, or both. The core 54 may be hollow or solid. Since fluid cannot travel through a solid ferrite core 54, side entrance ports 54 are provided in the tubing 24 to provide a fluid entrance in the event a solid core 54 is used. If a coil/core having a solid core were provided on the exit side of the valve, it is understood that exit ports would be provided on the tubing 28 in a similar manner. For the purpose of

example, the core 54 may be a Type 77 ferrite core, having a length of 10 mm and a 1 mm diameter. The coil 52 is 40 gauge wire (75 micron) of 100 turns wrapped around the core 54.

**[0068]** In yet another alternate embodiment, an inductive pickup coil is incorporated into the heater coil surrounding the thermally responsive polymer to provide a combined induction coil-heating element **55** as shown in Fig. 6b. A hollow ferrite rod **57** may be used to enhance electromagnetic coupling. In this embodiment, the inductive-coil heating element **55** is operated by application of the field of source **22** beyond the self resonant frequency resulting in core heating that can be used for valve actuation.

**[0069]** With reference to FIG. 7, there is shown yet another alternate embodiment of a system **60** configured to enable remote measurement of the pressure of pulmonary fluids, and to enable control over the release of fluids from the lungs. The system **60** is configured to measure the lung pressure distal to the valve **16** and tracheal pressure proximal to the valve **16**. In a preferred embodiment, the system **60** includes the components of the system **10** (bearing like reference numerals) and further includes multiple side inlet ports **62** and exit ports **64** that extend from the interior passageways to the exterior of the tubes **24** and **28** to avoid blockage of flow by the tracheal wall, a pressure transducer **66** located at the inlet, and a pressure transducer **68** located at the outlet, both of which are preferably MEMS diaphragm pressure transducers. An external data link **70**, such as a wired link extending from the transducers and thermocouples, is also included for collecting measured data during operation of the system **60**. The data link **70** may also be a wireless transmitter, and whether wired or wireless, it is understood that the various measuring components shown in Fig. 7 are electrically connected to the link **70** by wire or otherwise. The connections are not shown in Fig. 7, or other figures, to improve the visual clarity of the illustration.

**[0070]** The system **60** is configured for allowing the study of CDH in animal models and facilitates the study of correlations between lung pressure, volume, and lung development in the fetal pulmonary environment. The pressure information is relevant to the physiology of lung development, the effects of pressure on lung expansion, and the

role of pressure on cell differentiation. Also, based on the pressure differential across the system and the amount of restriction in the valve, the fluid flow rate through the open valve may be evaluated. In addition, temperature measurements provided by the thermocouples enable verification of the valve operation and remote power delivery, as well as maintenance of the temperature of the system within a desired range.

[0071] With reference now to FIGS. 8A and 8B, there is shown another embodiment in which a system **80** has an electromagnetic valve **82**. This embodiment uses the inductive power transfer system previous described. The valve **82** includes a mechanical spring **84** that urges a plug **86** against a valve seat **88** located on the exit end of a flow conduit **89** associated with the valve **82**. The plug **86** is attached to a permanent magnet **90**. A remote power induction coil **92** is provided for co-acting with the external field of source **22**, with a wire electrically connecting the coil **92** and a solenoid coil **94**. The solenoid coil **94** surrounds the spring **84** and magnetic core **90** to provide an electromagnet when powered to retract the plug **86** from the valve seat **88**. The valve **82** is normally closed under pressure supplied by the spring, as seen in FIG. 8A. However, application of the external field of source **22** to the coil **92** results in retraction of the plug **86** from the valve seat **88** to open the valve while the field of source **22** is applied to the coil **92**, as seen in FIG. 8B. Removal of the electric field will then enable the spring **84** to return the valve **82** to the closed position. Since a permanent magnet is utilized in this embodiment, it may be desired to rectify the received power.

[0072] As mentioned previously, the valve body **32** may be provided by an inflatable balloon of the type used in a tracheal occlusion procedure, embolization balloon procedure, balloon angioplasty or stent procedure, or other medical procedure requiring an inflatable balloon. In this regard, and with reference to FIGS. 9A and 9B, there is shown an inflation device **100** that may be utilized in conjunction with the system **80** or the other systems described herein and which facilitates inflation of a balloon **99** which provides the valve body **32**. The inflation device **100** includes a tube **102** having a lumen **104** on the end thereof configured for engaging the balloon **99**. The balloon **99** is configured to have a self-sealing valve **106** that permits inflation medium to flow from the inflation tube **102** and lumen **104** into the balloon **99** during an inflation step, but which remains in sealing contact with the exterior of the conduit **89** after the balloon **99** is

inflated. In this regard, inflation is conducted with the valve **82** in a closed state, such as seen in FIG. 9A. The balloon **99** is shown in a fully inflated state in FIG. 9B, with the valve **106** sealed.

[0073] FIGS. 10A, 10B and 10C show a further embodiment of an implant valve system **110** having a latch mechanism **112** that enables the valve to remain open when the electric field is not supplied. The system **110** includes the previously described electromagnetic valve **82** of FIGS. 8A and 8B, and also preferably includes the previously described balloon **99** and inflation device **100** of Figs. 9A and 9B. The latch mechanism **112** may be a mechanical latch or catch system associated with the moving portions of the valve to maintain them in a desired positional orientation. For example, as shown, the latch mechanism includes a catch **114** connected to the end of the magnetic core **90**, a translator **116** within the exit end to contact the catch **114** and cause rotation thereof, and a slot **118** within the exit end to receive the catch **114**.

[0074] As shown in FIG. 10A, the valve **82** is normally closed under pressure supplied by the spring in the absence of the electrical field being applied to the coil **92**. However, as seen in FIG. 10B, application of the external electrical field of source **22** to the coil **92** results in retraction of the plug **86** from the valve seat **88** to open the valve. As will be noted, a protrusion **120** of the catch **114** contacts an extension **122** of the translator **116** to cause the valve body **121** to rotate as the valve opens. When the source **22** is removed or turned off, as seen in FIG. 10C, the spring **84** urges the valve body **121** back toward a closed position. However, due to the rotated position of the valve body **121** from contact of the catch **114** with the translator **116**, the protrusion **120** is now positioned to be captured by the slot **118** to prevent closure of the valve, rendering the valve in the captured open state shown in FIG. 10C so that the valve remains open without application of the electric field. To close the valve, the electric field is re-applied and the valve body **121** is again rotated and this rotation frees the protrusion **120** from capture. In other words, the valve body **121** is rotated such that the protrusion **120** is no longer positioned to be captured by the slot **118**. Thus, when the electric field of source **22** is removed, the spring **84** urges the valve back to the closed position of FIG. 10A.

[0075] FIGS. 11A and 11B show yet another embodiment of an implant valve system **130** having a combined coil **132** that provides both energy reception and valve actuation functions. The coil **132** is a single coil that provides energy reception from the electric field of source **22** (which applies an RF field) and actuates operation of the valve. The system includes a ferrite material core **134** that is responsive to the source **22**. In the absence of the field of source **22**, the valve is closed as seen in FIG. 11A. When the coil **132** is activated by the source **22** as seen in FIG. 11B, a current is driven in the coil circuit which produces an RF magnetic field that is uniform near the center of the coil but has a field gradient at both ends. Ferrite material located in these field gradient regions will experience an attractive force, pulling the ferrite core **134** toward the coil **132**. With the core **134** positioned asymmetrically within the coil **132** as shown, the core **134** is pulled towards the coil **132**. When the pulling force on the core **134** exceeds the force of the spring **84**, the valve opens (FIG. 11B).

[0076] With reference to FIG. 12, there is shown a deflation device **140** which facilitates remote deflation of the balloon **99**. For example, as seen in FIG. 12, grooves or other channels **142** are provided for fluid to flow past the valve mechanism. A corresponding thermally activated system **144** is shown in FIG. 13, with the valve shown with an evacuated or otherwise insulating layer around the valve to reduce the amount of energy required to open the valve. The embodiments of FIGS. 12 and 13 are depicted to provide a remotely deflatable balloon structure. These embodiments may be utilized in circumstances wherein the balloon is surgically installed and inflated to occlude flow in a flow passage. Thereafter, the balloon may be remotely deflated to restore flow without the need for surgery. However, it will be understood that these structure may be incorporated with the previously described valve structures as well.

[0077] With reference to FIG. 14, there is shown a valve system **150** including a mechanical valve that is similar to the electromagnetically actuated systems described herein. In this embodiment, the valve is actuated by expansion of the thermally responsive polymer or other "smart" material such as shape memory alloy. In the thermally responsive polymer embodiment, the polymer swells at lower temperatures to close the valve. At higher temperatures, the polymer shrinks to open the valve. A membrane is provided to allow the polymer to absorb and exclude fluid.

[0078] With reference to FIGS. 15 and 16, it will be appreciated that the external electrical power source **22** may be operated in parallel or series resonance mode. For example, FIG. 15 shows the external power source **22** operable in a parallel resonant mode for transmitting power to the pickup coil **18** on the implanted valve. The source **20** includes an AC power source, the drive coil **22a**, the capacitor **22b**, and also preferably a resistive element **22c** for adjusting the transmitter circuit quality factor. However, it will be understood that part of or all of the resistive element **22c** may be composed of the resistance of the drive coil **22a**. The circuit associated with the pickup coil **18** includes the wire **40**, the capacitor **41**, and the heater **20**, and also preferably includes a resistive element **40b**. It will be understood, however, that part of or all of the resistive element **40b** may be composed of the resistance of the pickup coil **18**. FIG. 16 shows operation of the power source **22** in series mode. It will be understood that other combinations of parallel and series resonance may be employed. For example, the power transmission circuit in parallel resonance mode and the power reception circuit in series resonance, or vice versa.

[0079] FIGS. 17 and 18 illustrate another embodiment of the present invention.

[0080] A thermally actuated valve **200** includes a thermally actuated valve element **210** and an outer bore tubing **220** having an inner wall **224** defining a lumen **222**.

[0081] The valve element **210** includes an internalized heating element **214** and a thermally responsive polymer **212** grafted onto the surface of the internalized heating element **214**. The internalized heating element **214** includes a glass capillary and a heating element arranged within the glass capillary.

[0082] As described in further detail below, the valve element **210** is arranged within the lumen **222** of the outer bore tubing **220** to switch the valve **200** between at least two configurations to vary a flow rate of fluid through lumen **222**.

[0083] As an example, the valve element **210** is arranged within the lumen **222** of the outer bore tubing **220** to switch the valve **200** between a closed configuration and an open configuration.

[0084] In the closed configuration, the polymer **212** is at a base level temperature and is dimensioned to obstruct a flow of fluid through the lumen **222** of the outer bore tubing **220**. The base level temperature can, for example, be a physiological temperature (e.g., body temperature).

[0085] By raising the temperature of the polymer **212** above the base level temperature, the valve **200** is switched from the closed configuration to an open configuration. Specifically, raising the temperature of the polymer **212** above the base level temperature will cause the polymer **212** to collapse upon the internalized heating element **214** thereby establishing an annular flow path between the polymer **212** and the inner wall **224** of the outer bore tubing **220**.

[0086] A first exemplary method for fabricating the above-presented thermally actuated valve **200** is described below.

[0087] The first exemplary method of fabricating the valve **200**, includes a process of preparing an internalized heating element **214**. As stated above, the internalized heating element **214** can include a glass capillary upon which polymer **212** is grafted.

[0088] The glass capillary is first cleaned in a strong soap and rinsed thoroughly with water and dried. The glass capillary is then submersed in a volume of coating reagent including 1 mL of 3-(Trimethoxysilyl)propylmethacrylate in 200 mL of ethanol to which 6 mL of dilute acetic acid (1:10 glacial acetic acid:water) is added just before use. The solution is allowed to react with the glass capillary for 3 minutes, at which point the solution is poured off. The glass capillary, now modified, is then rinsed extensively with ethanol and allowed to dry. The modified glass capillary is then cut to size and placed within an outer bore tubing **220** (for example 1.75 mm i.d.) that has not been treated with 3-(trimethoxysilyl)propylmethacrylate). As an example, the outer bore tubing **220** can be a glass tube. In an exemplary configuration, the modified glass capillary can be arranged within the outer bore tubing **220** to form coaxial glass tubes.

[0089] The first exemplary method of fabricating the valve **200** further includes a process of grafting or covalently anchoring thermally responsive polymer **212** on to the surface of the internalized heating element **214** by, for example, polymerizing n-

isopropylacrylamide and acrylamide-based copolymers onto the reactive monomer 3-(trimethoxysilyl)propylmethacrylate.

**[0090]** The above-described coaxial glass tubes are placed in a solution of n-isopropylacrylamide mixed with dimethylacrylamide and methylene bis(acrylamide). This solution is degassed under an inert atmosphere (for example, nitrogen or argon). Ammonium persulfate and N,N,N',N'-tetramethylethylenediamine are then added to polymerize the copolymer. The copolymer that forms is covalently grafted to the surface of the glass capillary **214**, but is not covalently grafted onto the outer bore tubing **220**. Upon raising the temperature of polymer **212**, a collapse of the polymer **212** results from retention of the polymer **212** on the surface of the glass capillary **214** and detachment of the polymer **212** from the inner wall **224** of the outer bore tubing **220**, forming a flow path in the resultant annulus.

**[0091]** An example of a process of grafting thermally responsive polymer **212** to the modified glass capillary **214** is provided herein. The above-described coaxial glass tubes are placed in a mixture of 200 microliters of n-isopropyl acrylamide (50 mg/mL), 2 microliters of methylene bis(acrylamide) (50 mg/mL), and 6 microliters of dimethylacrylamide in phosphate buffered saline solution. This solution is degassed under nitrogen for 2 hrs and 5 microliters of ammonium persulfate are added (50 mg/ml in water). The solution is stirred and 3 microliters of a 1:10 dilution of N,N,N',N'-tetramethylethylenediamine (10 microliters in 100 microliters water) are added. The reaction is allowed to proceed overnight under nitrogen purge. The coaxial glass tubes are then removed from the reaction and placed under water heated to 65°C, upon which the thermally reactive polymer **212** shrinks away from the inner wall of the outer bore tubing **220** and collapses upon the outer wall of the glass capillary. In an exemplary modification, the glass capillary and grafted polymer **212** can be removed from the outer bore tubing **220** and placed into another tube of interest.

**[0092]** Variation of polymer formulations can be used to adjust the actuation temperature of the thermally responsive polymer **212**. For example, copolymers of poly-n-isopropyl acrylamide and dimethylacrylamide can be used to achieve transition temperatures below which the polymer **212** expands and above which it contracts,

ranging from approximately 32 °C to 50°C (0 mole fraction DMAA to 0.5 mole fraction DMAA). An exemplary embodiment for biomedical implants is a copolymer of poly-n-isopropyl acrylamide and dimethylacrylamide with a mole fraction of dimethylacrylamide of 0.3 to 0.45. This polymer formulation provides an actuation temperature ranging from approximately 38 °C to 46 °C. As such, the thermally actuated valve **200** is in an expanded state at normal physiological temperature and can be actuated to collapse at temperatures slightly above physiological temperature.

[0093] A second exemplary method of fabricating the above-described thermally actuated valve **200** is provided herein. As illustrated in FIG. 18, the second exemplary fabrication method includes generating copolymers **212a** of thermally responsive polymers using surfactant free polymerization and grafting the resultant spherical copolymers **212a** onto the internalized heating element **214**. One approach is to mix solutions of n-isopropylacrylimide and acrylic acid with methylene bis(acrylamide) and to purge the solution with nitrogen. Ammonium persulfate is then added and the solution is stirred and elevated to 70 °C under an inert environment. This results in the generation of spherical polymers **212a** which can then be covalently grafted onto the surface of an internalized heating element **214**. In this case, the copolymerization of acrylic acid provides carboxylic acid groups which can be grafted onto primary amines using carbodiimide chemistry. For example, the glass surface of the internalized heating element **214** can be functionalized by vapor or liquid priming with 3-aminopropyltriethoxysilane (APTES) to provide pendant primary amines. An amide bond can then be formed between the pendant amine and the carboxylic acid of the pnipam-co-paa polymer microspheres using the crosslinking agent, 1-ethyl-3-(3-dimethylaminopropyl) carbodiimide. In this configuration, the spheroids of thermally responsive polymer **212a** are immobilized onto the surface of the internalized heating element **214**. If the resulting thermally activated valve element **210** is placed within another tube of interest, the expansion and collapse of the spheroids of thermally responsive polymer **212a** results in decreasing and increasing flow, respectively, through the tube of interest in response to cooling and heating and heating of the spheroids of thermally responsive polymer **212a**.

[0094] FIG. 19 illustrates another embodiment of the present invention.

[0095] A thermally activatable valve **300** includes a valve element **310** further including a thermally responsive polymer **312** and a solid element **316** attached to the polymer **312**. The valve element **310** is arranged in proximity to a valve seat taking the form of a fluidic inlet/outlet **330**. The valve element **310** is configured to switch the valve **300** between at least a closed configuration and an open configuration.

[0096] In the closed configuration, the polymer **312** of valve element **310** is in an expanded state and dimensioned to urge solid element **316** against fluidic inlet/outlet **330** to restrict the flow of fluid through fluidic inlet/outlet **330**.

[0097] Upon heating of the polymer **312**, the valve element **310** switches the thermally actuated valve **300** to an open configuration. Specifically, upon heating, the polymer **312** will collapse to remove the solid element **316** from the fluidic inlet/outlet **330** thereby causing less flow restriction to the fluidic inlet/outlet **330**.

[0098] Exemplary configurations of structural features for actuating the valve **300** is described below.

[0099] In a first configuration, the valve **300** can be actuated by Joule heating. Conductive materials may be placed in thermal contact with the polymer **312**. For example, conductive materials may be placed within, around, and/or enmeshed in the polymer **312**. Passage of DC or AC current through the conductive materials release heat, thereby raising the temperature of the conductive materials and the polymer **312**.

[00100] In a second configuration, the valve **300** can be actuated by induction heating. Conductive material may be placed in thermal contact with the polymer **312**. The conductive material is heated by electromagnetic induction, where eddy currents are generated within the conductive material and resistance leads to Joule heating of the conductive material.

[00101] The conductive material may be a continuous conductive material internal or external to the polymer **312**, or the conductive material may be discontinuous conductive materials embedded within or around the polymer **312** such as discrete nano- and microspheres of metals or metallic conductors. Induction heating may also be

utilized by incorporating conductive material within or around the polymer **312** such as within a glass encapsulated internal heater as described above.

[00102] Magnetic materials may be incorporated within, around, or enmeshed in the polymer **312** to provide heating via induction heating. These magnetic materials may include nano- and microparticles of magnetic materials which are heated by inductive heating. These magnetic materials may include Curie thermoregulated materials such that heating can be controlled by the transition of these magnetic materials from ferro/ferri magnetic below the Curie point to paramagnetic above the Curie temperature.

[00103] In a third configuration, the valve **300** can be actuated by ultrasonic excitation. Ultrasonic energy is focused on or around the valve **300** to generate heat in the tissue surrounding, or the materials including and surrounding the valve **300**.

[00104] Enhanced heating can be achieved by placing ultrasound contrast agents surrounding the polymer **312** such that the absorption of ultrasonic energy is enhanced in the region surrounding the polymer **312**.

[00105] An embodiment for medical implantation is to place the valve element **310** within the lumen of a tube which in turn is surrounded by an inflatable balloon. To deploy the system as an implant, the system is placed in the desired tissue and the balloon is then inflated with an ultrasound contrast agent or any material which has higher absorbance of ultrasound energy than human tissue. The inflation media can then be used as a target for enhanced absorption of ultrasound excitation, and will therefore be heated more effectively than surrounding tissue. Heating of the inflation media can then be used to actuate the embedded polymer **312**.

[00106] In a fourth configuration, the valve **300** can be actuated by infrared or near-infrared heating. In particular, near-infrared heating may be beneficial due to the significant tissue penetration depth of near infrared at wavelengths within a therapeutic window of 700-1200 nm.

[00107] As an example of near infrared heating, gold nanospheres are incorporated into the polymeric matrix, or packed in an internal heating tube within a valve element

**310.** These gold nanospheres may then be heated by near infrared energy, including multiphoton excitation of multiple convergent rays of near infrared radiation.

**[00108]** In a fifth configuration, the valve **300** can be actuated by physiological situations. Examples of physiological situations that can be harness to actuate the valve **300** include, but are not limited to, elevated body temperatures due to fever, infection, microbial process, increased activity/metabolism of cells and tissue including exercise and physical exertion, and increased growth/proliferation/metabolism of cells, including tumore cells.

**[00109]** In a sixth configuration, the valve **300** can be actuated by convective or conductive heating of the tissue surrounding the valve 300.

**[00110]** Another embodiment of the present invention will be described below with reference to the above-presented embodiments.

**[00111]** The thermally reactive polymer valve systems described in the above-presented embodiments can be modified to be in either a normally closed or a normally open state. For example, a copolymer formulation of 30% mole fraction dimethylacrylamide and 70% n-isopropylacrylamide will provide an expanded polymer at normal physiological temperature (37°C) that will collapse upon delivery of heat to raise the polymer temperature to 38°C. In a contrasting example, a polymer including only poly-n-isopropyl acrylamide will be in a collapsed state at physiological temperature, but will be in an expanded state when cooled.

**[00112]** It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both combinations and subcombinations of the various features described hereinabove, as well as variations and modifications thereof that are not in the prior art, which would occur to persons skilled in the art upon reading the foregoing description.

**[00113]** It will be appreciated that the valve systems of the various embodiments described herein may be suitably configured for use in the treatment and study of CDH as well as other conditions wherein treatment or study involves controlling the flow of fluid

in physiological channels. These other conditions include, for example, delivery of therapeutic agents, the movement of reproductive materials in the reproductive tracts of males and females, blood flow to male reproductive organs, the release of bile from the gall bladder or liver, the release of insulin from the pancreas.

**What is claimed is:**

1. A valve implant system positionable within a flow passage comprising:  
an inlet, an outlet, a thermally activatable valve between the inlet and the outlet, and a power source for thermally activating the valve;  
wherein the valve is normally in a “closed” state to restrict fluid from traveling from the inlet through the valve and out the outlet,  
wherein the valve is placed in an “open” state by applying heat to the valve to activate the valve to the “open” state, and  
wherein upon removal of the heat, the valve returns to the “closed” state.
2. The system of claim 1 further comprising a power transmitter for transmitting power to the power source.
3. The system of claim 2, wherein the power transmitter is operated in series or parallel resonance mode.
4. The system of claim 1 wherein the power source is a receiver of electromagnetic energy and further comprising a power transmitter for transmitting electromagnetic energy to the power source.
5. The system of claim 1 wherein the power source is a coil and further comprising a power transmitter for transmitting electromagnetic energy to the power source.
6. The system of claim 1 wherein the power source is a coil and further comprising a RF power transmitter for transmitting electromagnetic energy in the RF frequency range to the power source.
7. The system of claim 1, wherein the power source is operated in series or parallel resonance mode.
8. A valve implant system configured for being disposed within a flow passage comprising:  
a left end tube having a passageway;  
a left intermediate tube having a first end, a second end and an passageway communicating with the passageway of the left end tube, the first end of the left intermediate tube being secured to the left end tube;

- a balloon secured to the second end of the left intermediate tube and having a diameter sized to be positioned within and blocking the flow passage;
  - a valve tube having a passageway and first and second ends, the passageway of the valve tube communicating with the passageway of the left intermediate tube, the first end of the valve tube being connected to the second end of the left intermediate tube;
  - a polymer disposed in the valve tube, the polymer being selected to expand at ambient temperature and shrink when heated from ambient temperature, the polymer being configured and disposed for blocking the passageway of the valve tube at ambient temperatures and for shrinking when the polymer is heated to open the passageway in the valve tube;
  - a heater disposed proximate the polymer for heating the polymer;
  - a power supply for providing power to the heater to cause the heater to heat the polymer and open the passageway in the valve tube;
  - a right intermediate tube having first and second ends and a passageway, the first end of the right intermediate tube being connected to the balloon and the passageway of the right intermediate tube communicating with the passageway of the valve tube at the second end of the valve tube; and
  - a right end tube disposed on the second end of the right intermediate tube;
- whereby when the polymer is heated, an open composite passageway is formed through the left and right end tubes, the left and right intermediate tubes and the valve, and when the polymer is unheated and attains ambient temperature the polymer expands and the composite passageway is blocked by the polymer.
9. The system of claim 8, further comprising side ports formed in the sides of the left and right intermediate tubes for allowing fluid flow between the passageways and the exteriors of the left and right intermediate tubes.

10. The system of claim 8, further comprising a MEMS diaphragm pressure transducer mounted to sense the pressure in the flow passage.
11. The system of claim 8, further comprising a communication link for transmitting information corresponding to the pressure sensed by the pressure transducer.
12. The system of claim 8, further comprising temperature sensors mounted to sense the temperature of the heater.
13. The system of claim 8, further comprising a communication link for transmitting information corresponding to the temperature sensed by the temperature transducer.
14. The system of claim 8, further comprising temperature sensors mounted to sense the temperature of the polymer.
15. The system of claim 8, further comprising a communication link for transmitting information corresponding to the temperature sensed by the temperature transducer.
16. The system of claim 8, further comprising fluid flow sensors configured to sense the flow of fluids through the valve.
17. The system of claim 8, wherein the power supply is operated in series or parallel resonance mode.
18. The system of claim 8, wherein the balloon includes a self-sealing valve and the system further includes an inflation tube so that an inflation medium is permitted to flow into the balloon through the self-sealing during an inflation step, with the valve thereafter maintaining the balloon sealed against deflation.
19. An implant system for being disposed within a flow passage for selectively occluding flow through the flow passage, the system comprising: a tube within the flow passage, an inflated balloon within the flow passage in flow communication with the tube, and a valve associated with the tube and remotely activatable for deflation of the inflated balloon to restore flow through the flow passage.
20. A valve implant system positionable within a flow passage comprising:
  - an inlet, an outlet, and a valve between the inlet and outlet, the valve including an energy receiving coil and an actuation coil;

wherein the valve is normally in a “closed” state to restrict fluid from traveling from the inlet through the valve and out the outlet,

wherein the valve is placed in an “open” state by applying an external electrical field to the energy receiving coil to activate the actuation coil to place the valve in an “open” state.

21. The valve implant system of claim 20, wherein the valve returns to the “closed” state when the external electrical field is removed.
22. The valve implant system of claim 20, wherein the valve remains in the “open” state when the external field is removed, but returns to the “closed” state when the external electrical field is subsequently applied.
23. The valve implant system of claim 20, wherein the energy receiving coil and the actuation coil are separate coils.
24. The valve implant system of claim 20, wherein the energy receiving coil and the actuation coil are a single coil.
25. A thermally actuated valve comprising:
  - an insertion portion comprising an inside wall defining a lumen therethrough;
  - a thermal actuating element; and
  - a thermally responsive polymer arranged within the lumen of the insertion portion, the thermally responsive polymer comprising at least two operative configurations, wherein the thermally responsive polymer is configured to switch between the at least two operative configurations in response to a change in temperature of the thermally responsive polymer applied by the thermal actuating element to vary a flow rate of fluid through the lumen.
26. The thermally actuated valve of claim 25, wherein the thermally responsive polymer is anchored to the inside wall of the insertion portion to form an annulus defining a variable flow path through the open region of the annulus.
27. The thermally actuated valve of claim 26, wherein the thermal actuating element comprises:
  - a heating element disposed proximate the thermally responsive polymer for heating the thermally responsive polymer; and

a power supply for providing power to the heating element.

28. The thermally actuated valve of claim 25, wherein:

the thermally responsive polymer is positioned within the lumen of the insertion portion to define a variable flow path between the thermally responsive polymer and the inside wall of the insertion portion.

29. The thermally actuated valve of claim 28, wherein the thermal actuating element comprises a heating element in thermal contact with the thermally responsive polymer, the heating element being adapted to be heated by Joule heating.

30. The thermally actuated valve of claim 28, wherein the thermal actuating element comprises a heating element in thermal contact with the thermally responsive polymer, the heating element being adapted to be heated by induction heating.

31. The thermally actuated valve of claim 28, wherein the thermal actuating element comprises a heating element in thermal contact with the thermally responsive polymer, the heating element being adapted to be heated by ultrasonic excitation.

32. The thermally actuated valve of claim 28, wherein the thermal actuating element comprises a heating element in thermal contact with the thermally responsive polymer, the heating element being adapted to be heated by infrared or near-infrared heating.

33. The thermally actuated valve of claim 25, further comprising:

a valve seat element placed in the lumen of the insertion portion to define a variable flow path;

a solid element, arranged relative to the thermally responsive polymer, wherein the thermally responsive polymer is configured to change in dimension in response to a temperature change applied by the thermal actuating element to position the solid element with respect to the valve seat element to vary a flow rate of fluid through the lumen.

34. A valve implant system comprising:

a thermally activated valve comprising:

an insertion portion comprising an inside wall defining a lumen therethrough;

a thermal actuating element; and

a thermally responsive polymer arranged within the lumen of the insertion portion, the thermally responsive polymer comprising at least two operative configurations, wherein the thermally responsive polymer is configured to switch between the at least two operative configurations in response to a change in temperature of the thermally responsive polymer applied by the thermal actuating element to vary a flow rate of fluid through the lumen;

an inlet in communication with a first opening of the lumen of the insertion portion of the thermally activated valve; and

an outlet in communication with a second opening of the lumen of the insertion portion of the thermally activated valve.

35. The valve implant system of claim 34, wherein the thermally responsive polymer is anchored to the inside wall of the insertion portion to form an annulus defining a variable flow path through the open region of the annulus.

36. The valve implant system of claim 34, wherein the thermal actuating element comprises:

a heating element disposed proximate the thermally responsive polymer for heating the thermally responsive polymer; and

a power supply for providing power to the heating element.

37. The valve implant system of claim 34, wherein:

the thermally responsive polymer is positioned within the lumen of the insertion portion to define a variable flow path between the thermally responsive polymer and the inside wall of the insertion portion.

38. The valve implant system of claim 37, wherein the thermal actuating element comprises a heating element in thermal contact with the thermally responsive polymer, the heating element being adapted to be heated by Joule heating.

39. The valve implant system of claim 37, wherein the thermal actuating element comprises a heating element in thermal contact with the thermally responsive polymer, the heating element being adapted to be heated by induction heating.

40. The valve implant system of claim 37, wherein the thermal actuating element comprises a heating element in thermal contact with the thermally responsive polymer, the heating element being adapted to be heated by ultrasonic excitation.

41. The valve implant system of claim 37, wherein the thermal actuating element comprises a heating element in thermal contact with the thermally responsive polymer, the heating element being adapted to be heated by infrared or near-infrared heating.
42. The valve implant system of claim 34, further comprising:
- a valve seat element placed in the lumen of the insertion portion to define a variable flow path;
  - a solid element, arranged relative to the thermally responsive polymer, wherein the thermally responsive polymer is configured to change in dimension in response to a temperature change applied by the thermal actuating element to position the solid element with respect to the valve seat element to vary a flow rate of fluid through the lumen.

1/13

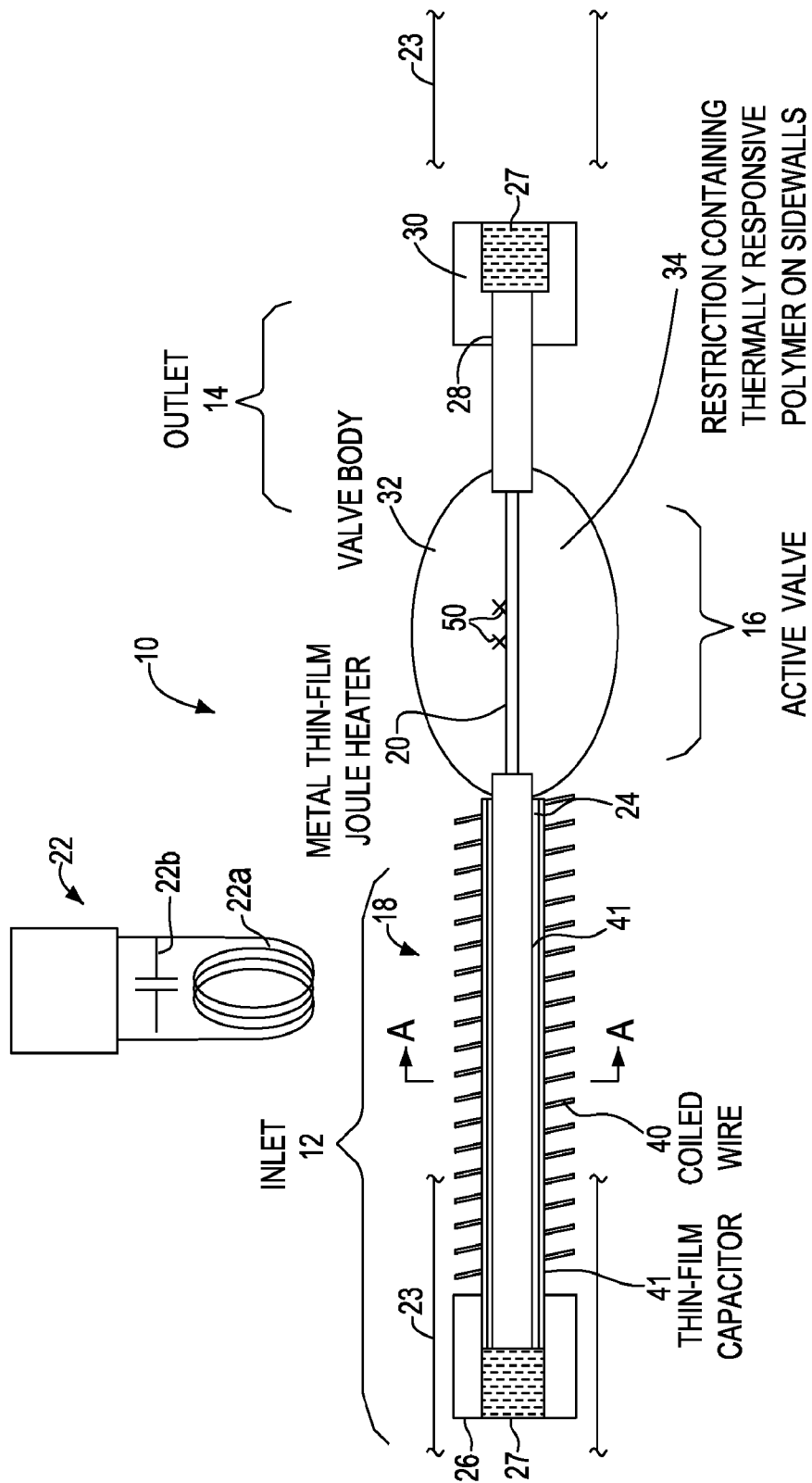


FIG. 1

2/13

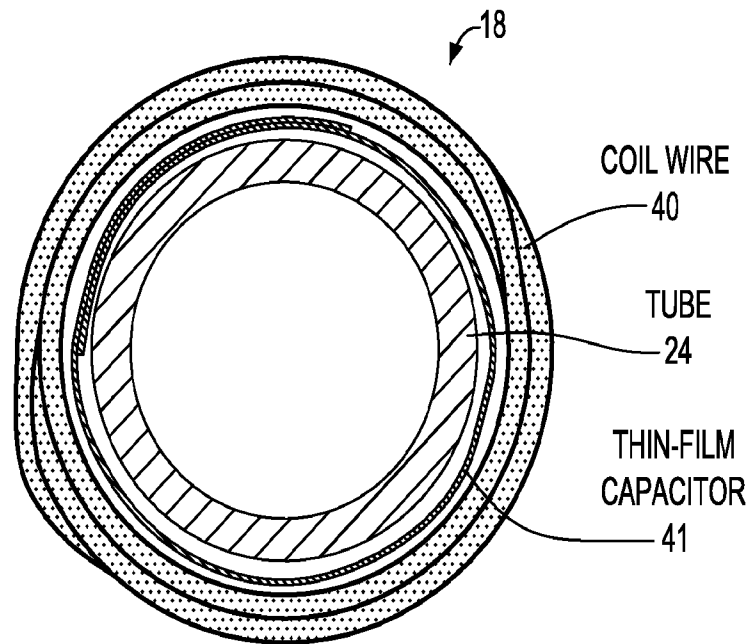


FIG. 1A

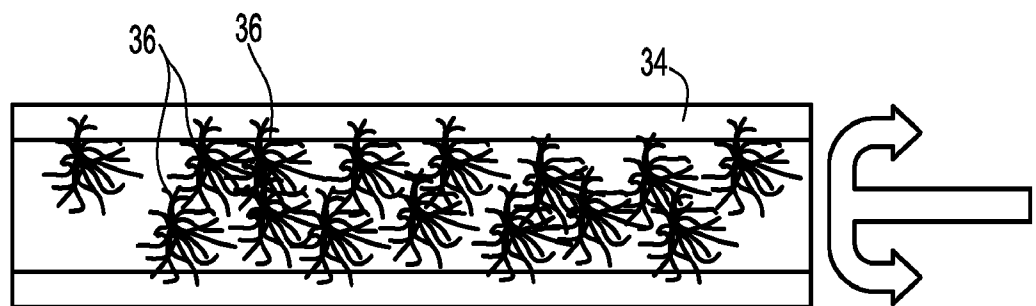


FIG. 2A

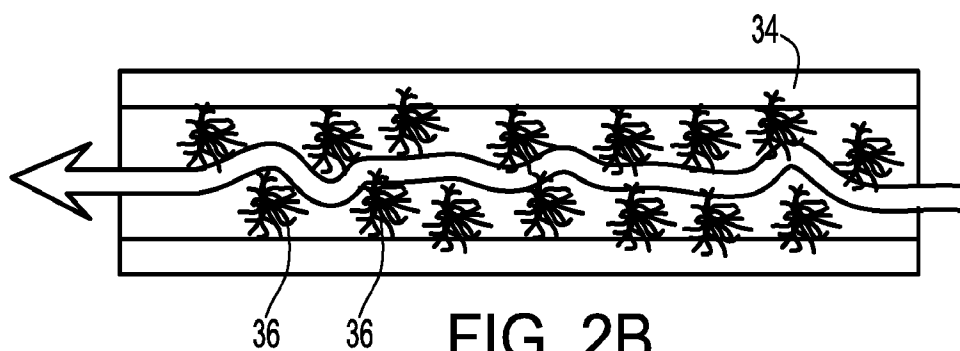


FIG. 2B

3/13

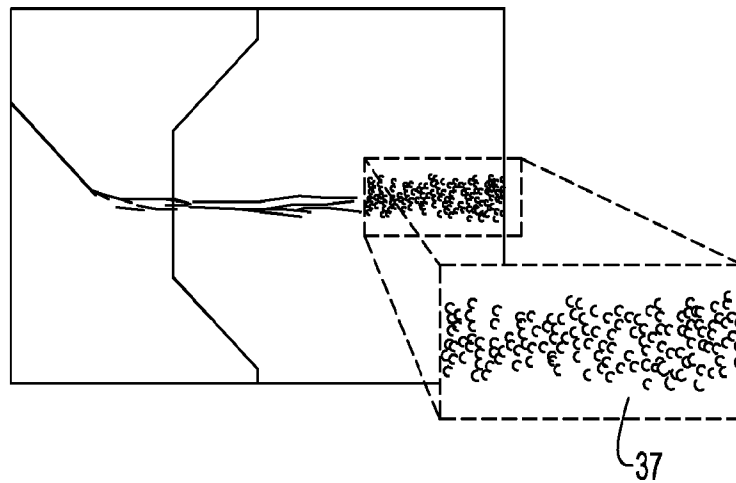


FIG. 3

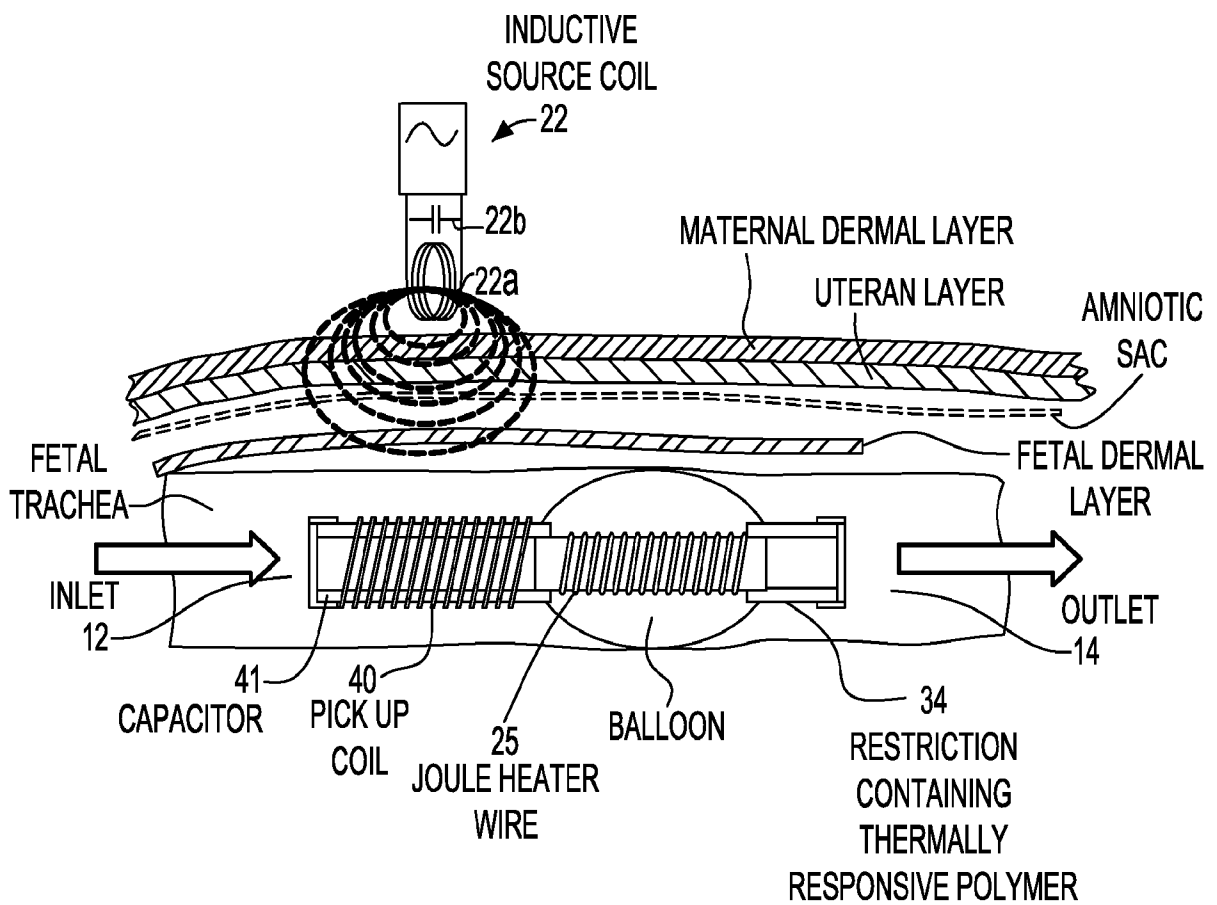


FIG. 4

4/13

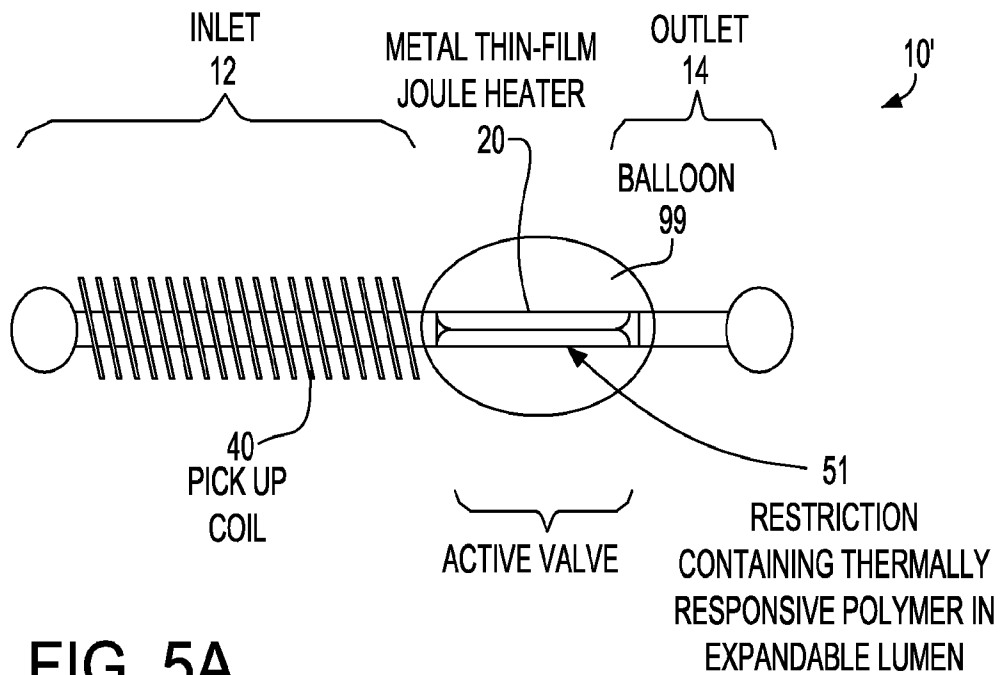


FIG. 5A

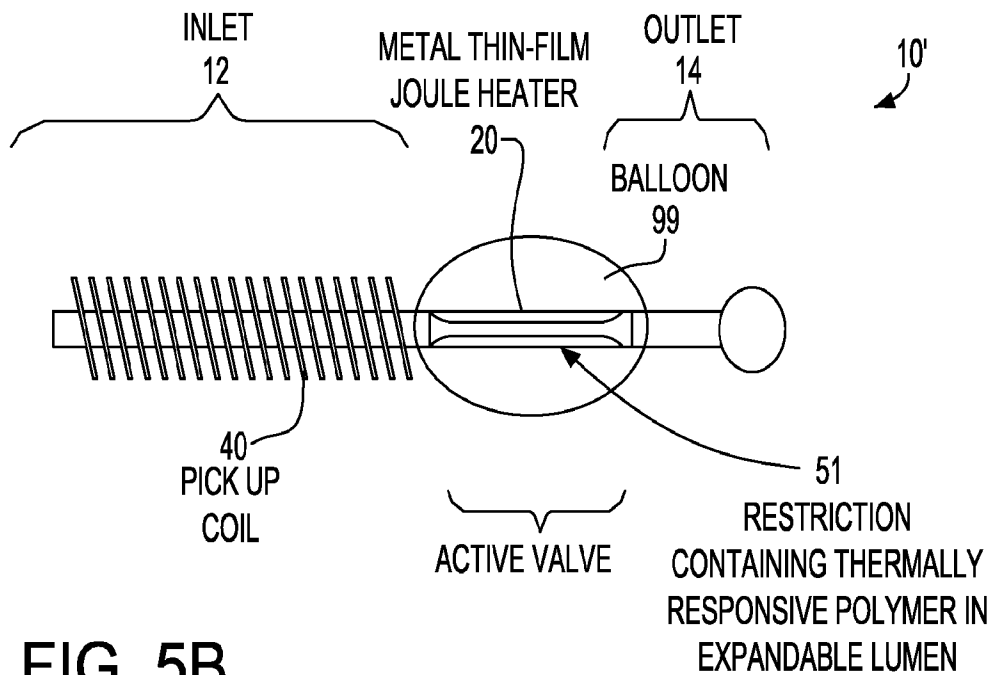


FIG. 5B

5/13

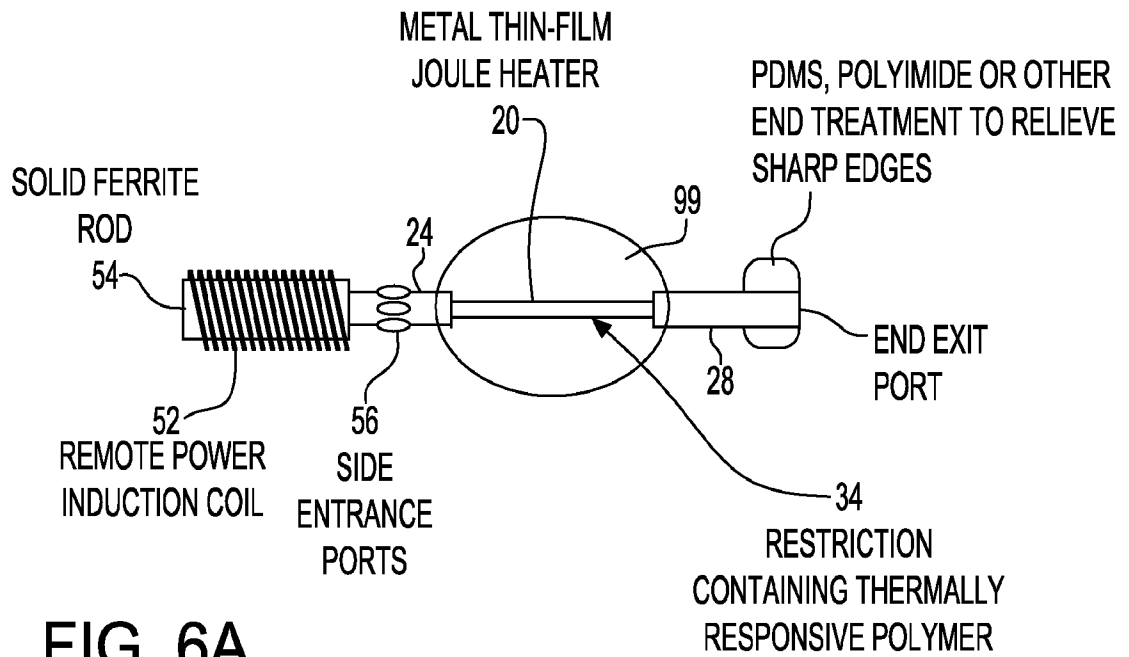


FIG. 6A

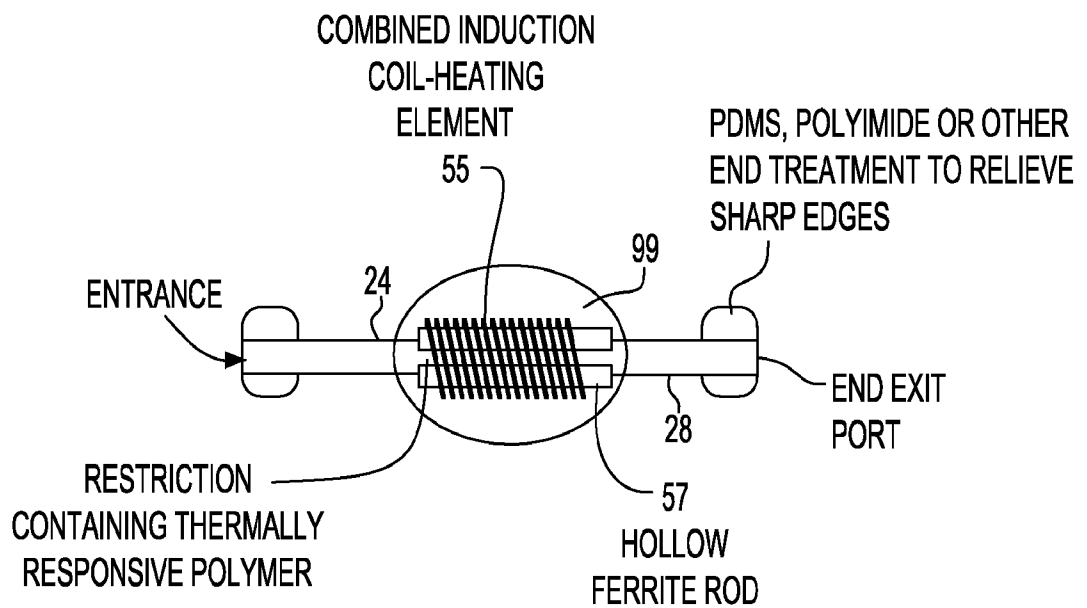


FIG. 6B

6/13

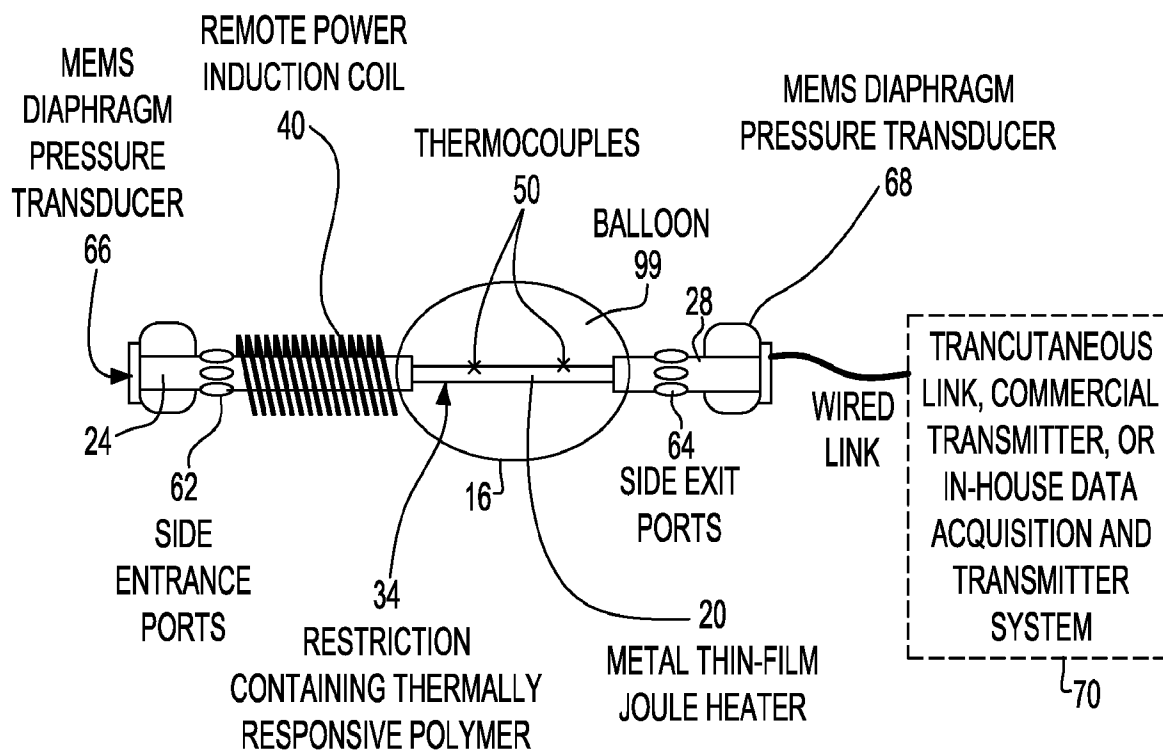
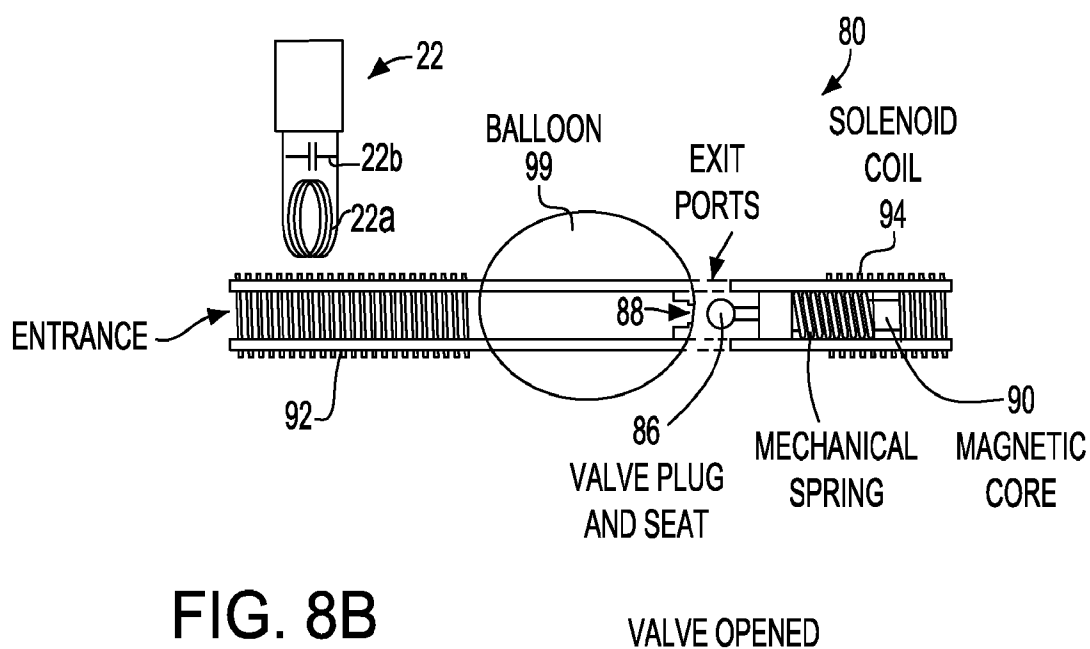
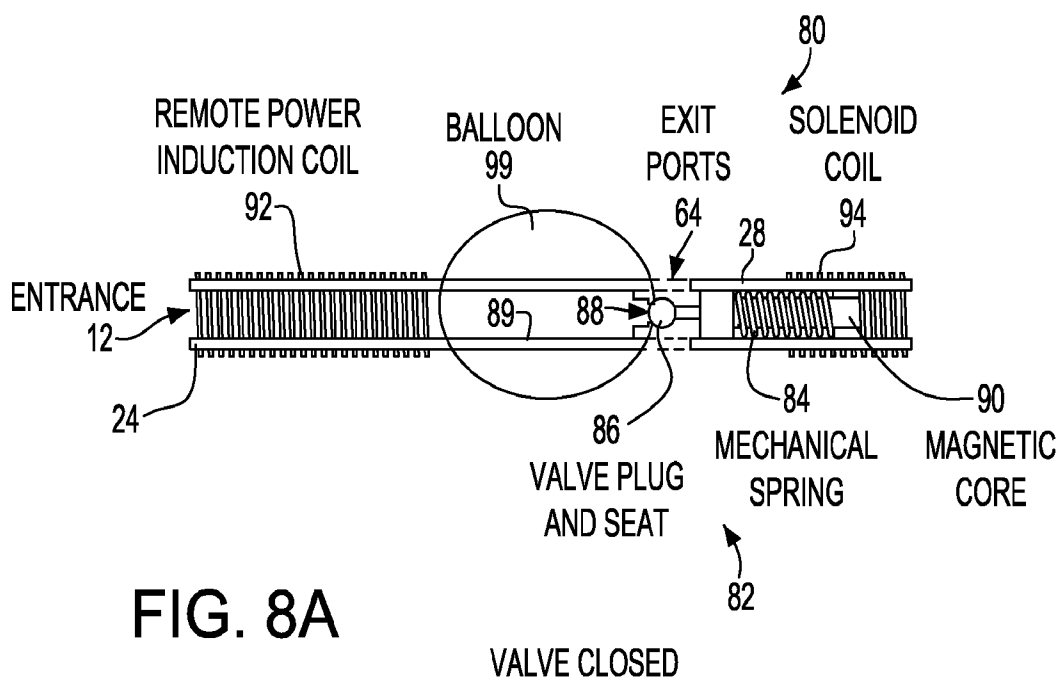


FIG. 7

7/13



8/13

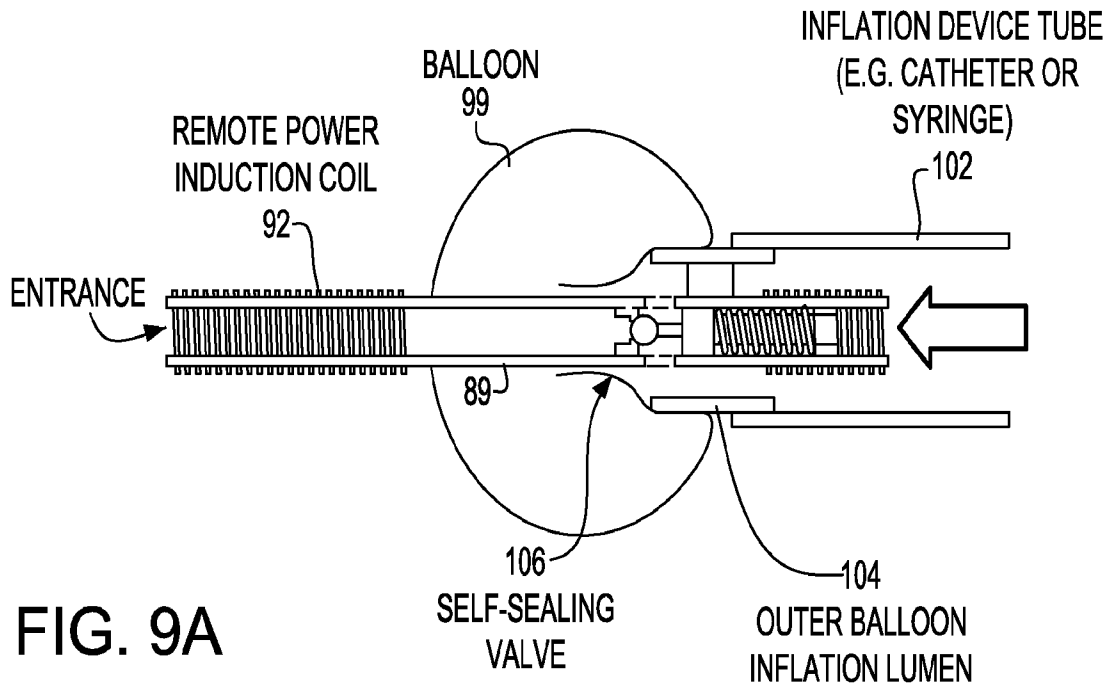


FIG. 9A

INFLATION OCCURS WHILE VALVE IS  
CLOSED THROUGH AN OUTER LUMEN

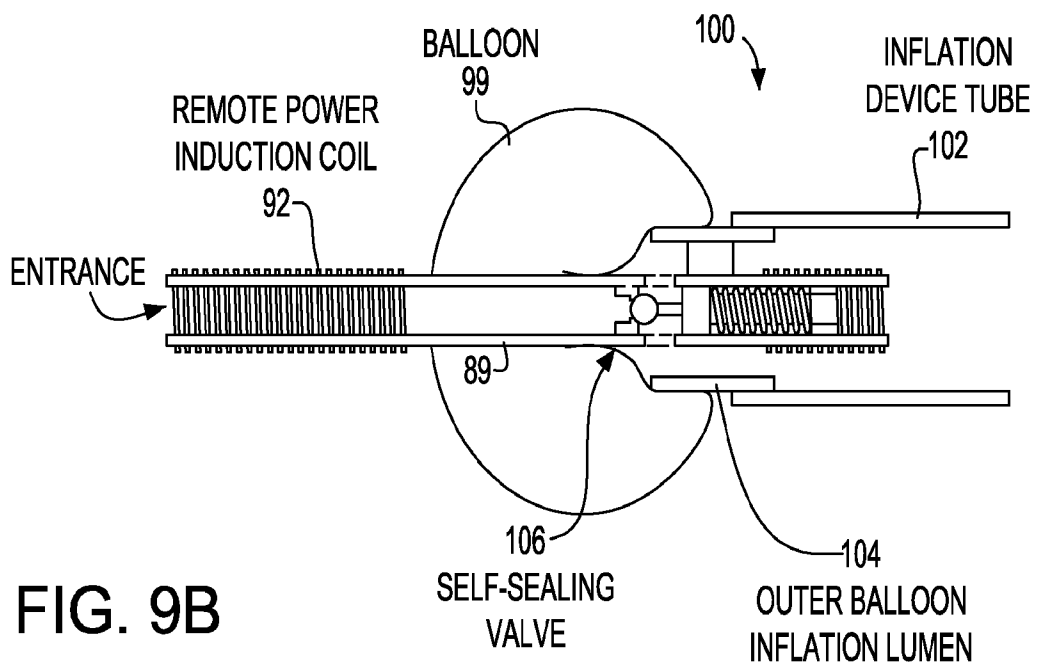


FIG. 9B

9/13

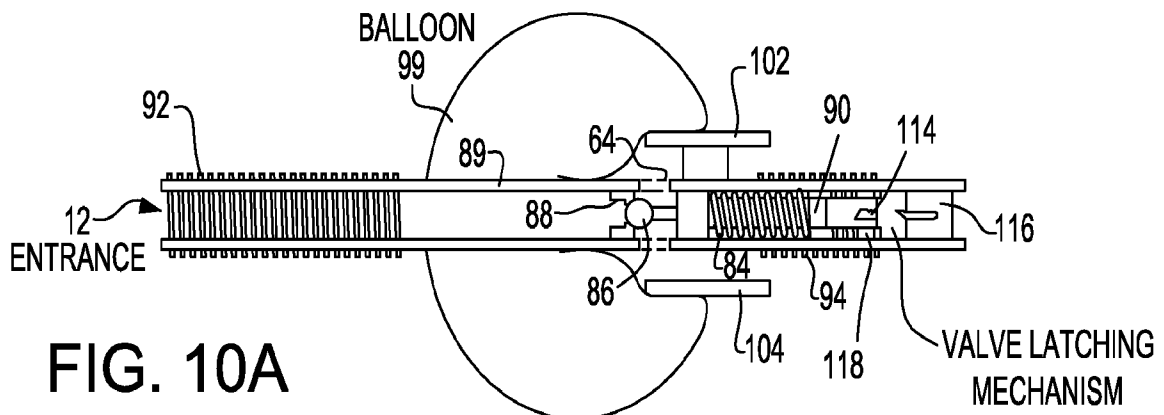


FIG. 10A

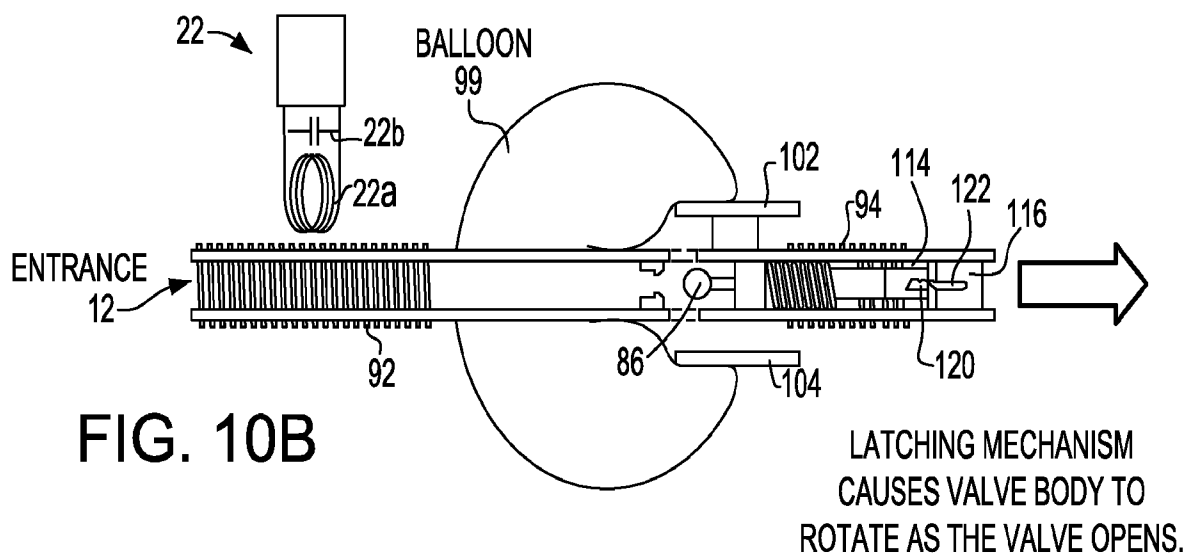


FIG. 10B

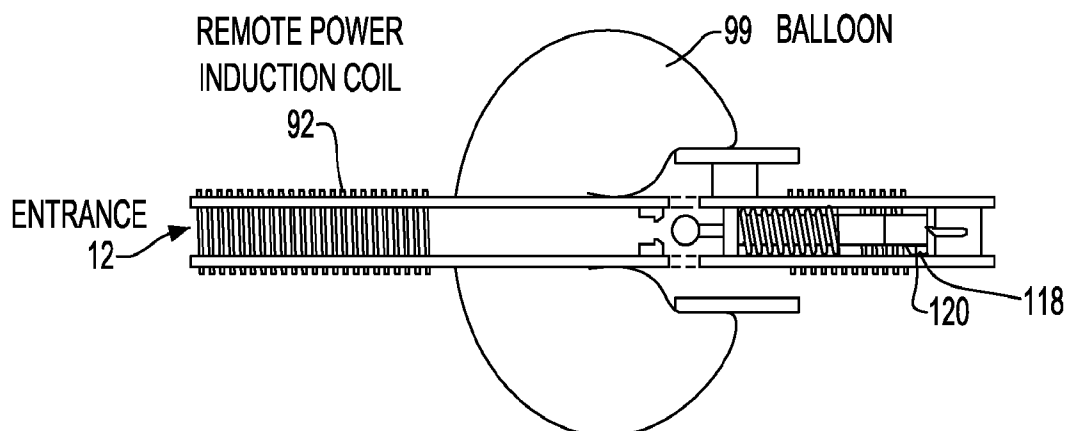


FIG. 10C

VALVE LATCHING MECHANISM CAUSES BODY TO ROTATE INTO A  
SLOT THAT HOLDS THE VALVE OPEN UNTIL NEXT ACTUATION  
CAUSES IT TO ROTATE TO CLOSED POSITION.

10/13

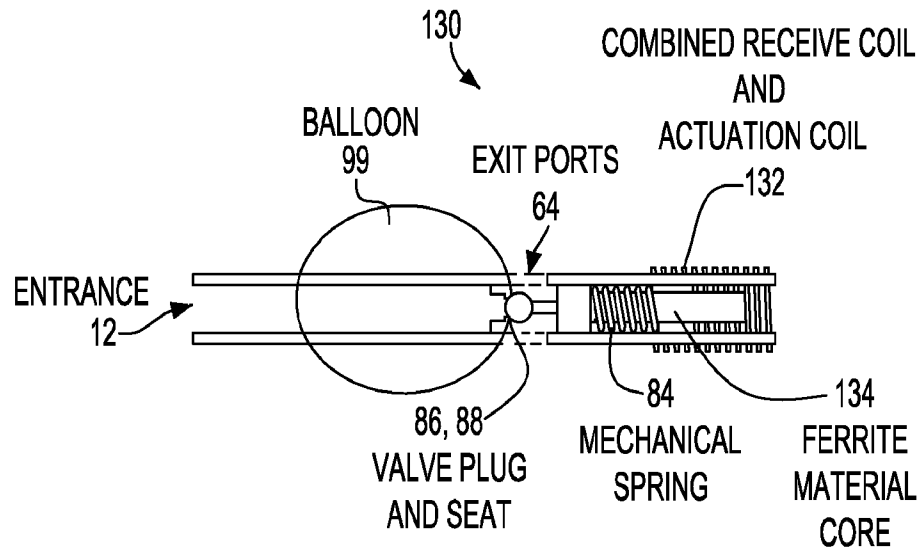


FIG. 11A

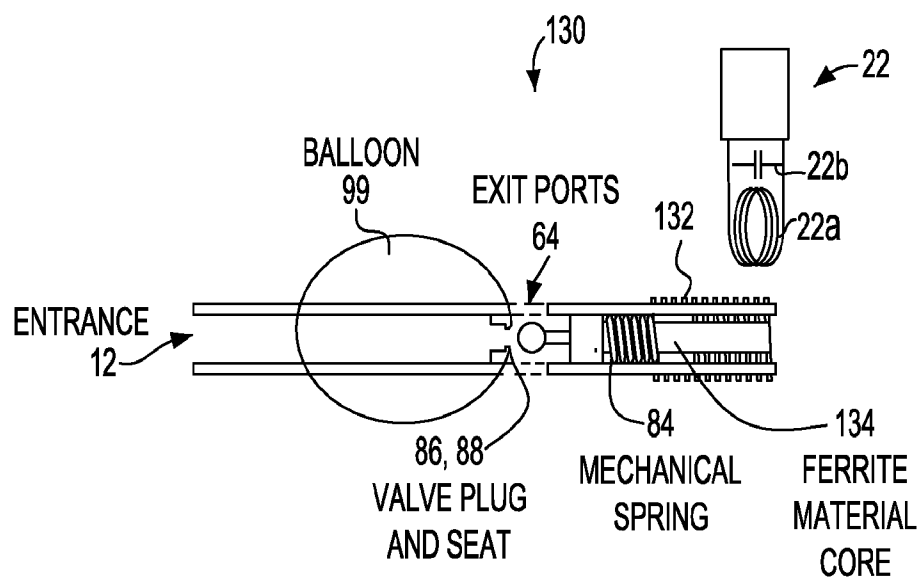


FIG. 11B

11/13

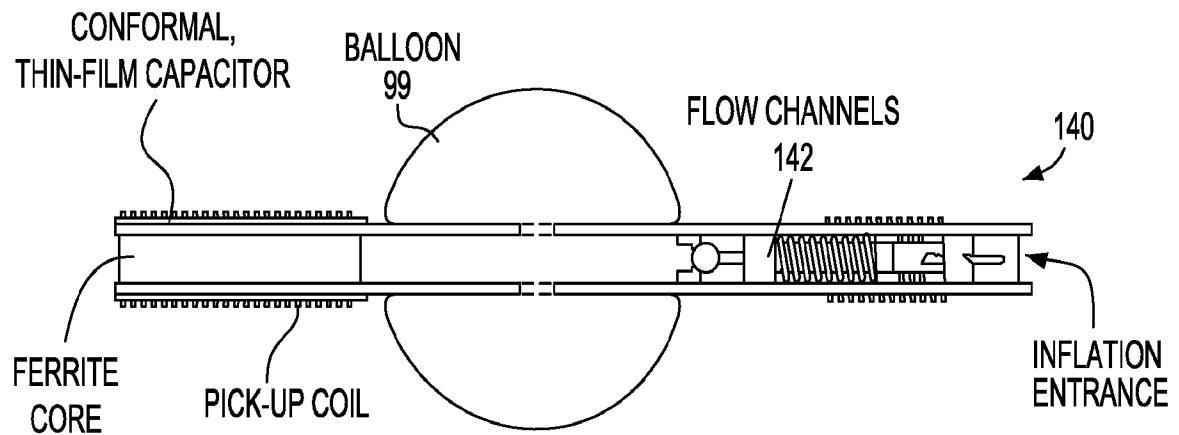


FIG. 12

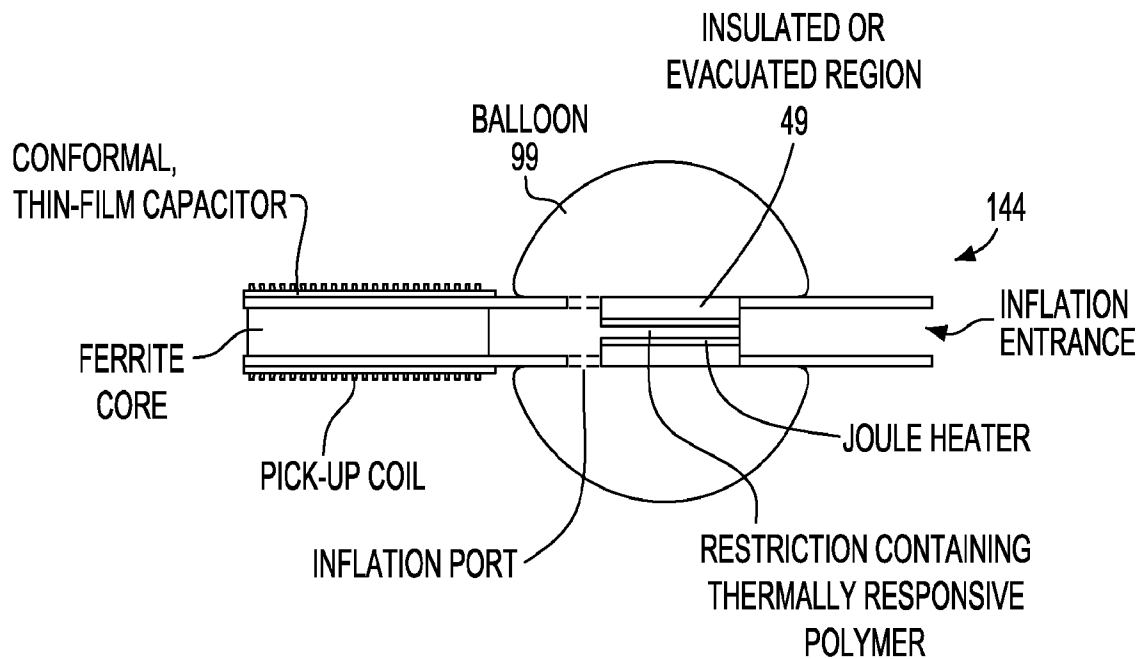


FIG. 13

12/13

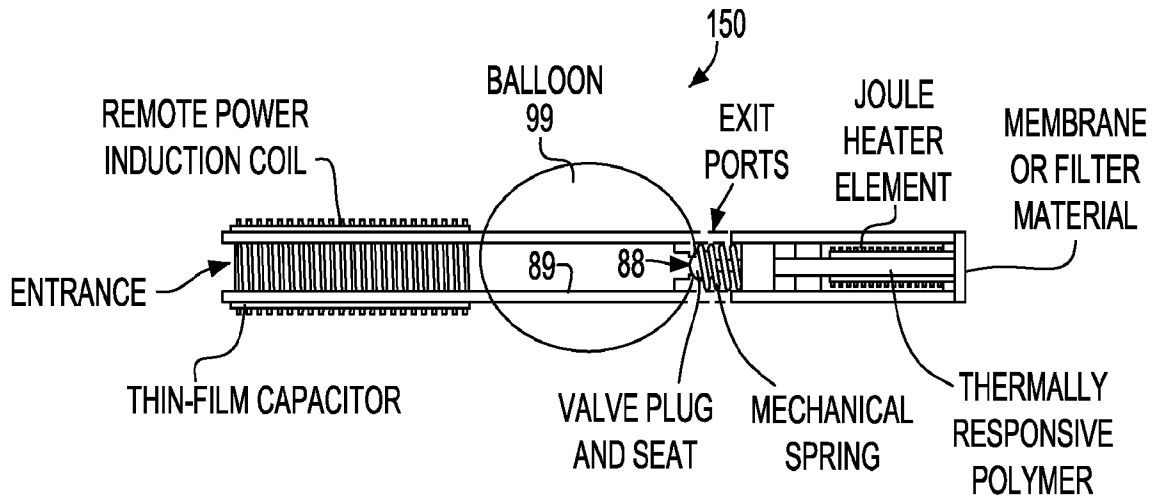


FIG. 14

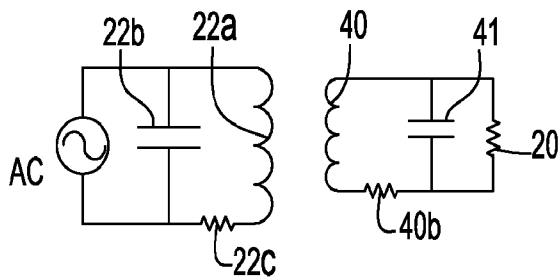


FIG. 15

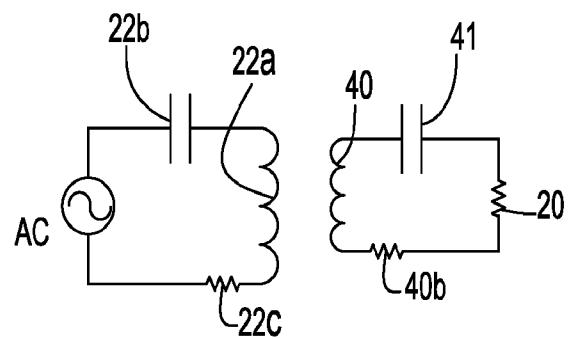


FIG. 16

13/13

FIG. 17

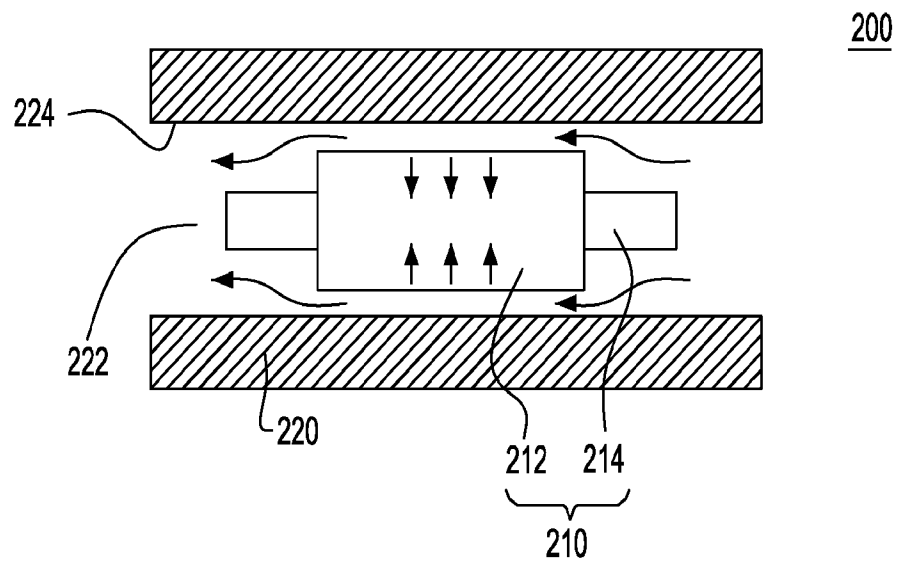


FIG. 18

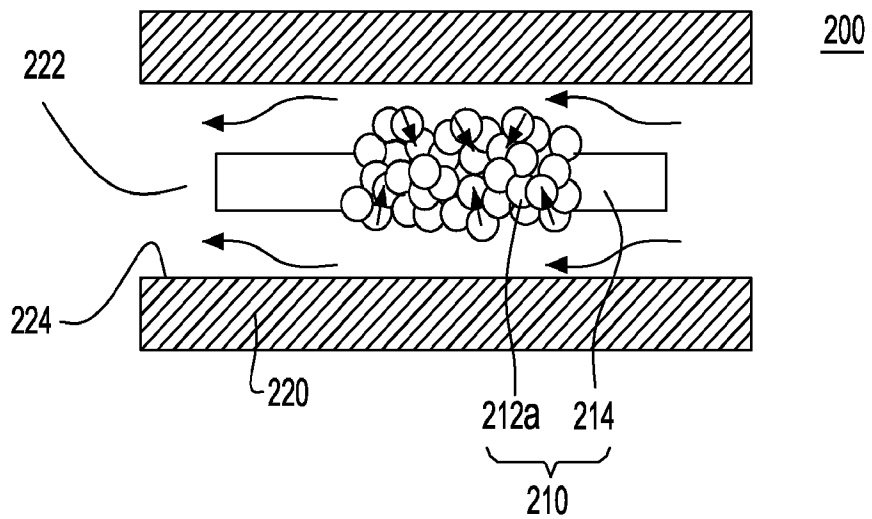


FIG. 19

