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(54) **ULTRASOUND TRANSDUCER AND USES THEREOF**

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A61B 8/14 (2006.01)

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USPC **600/459**; 600/437

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USPC 600/437–469
See application file for complete search history.

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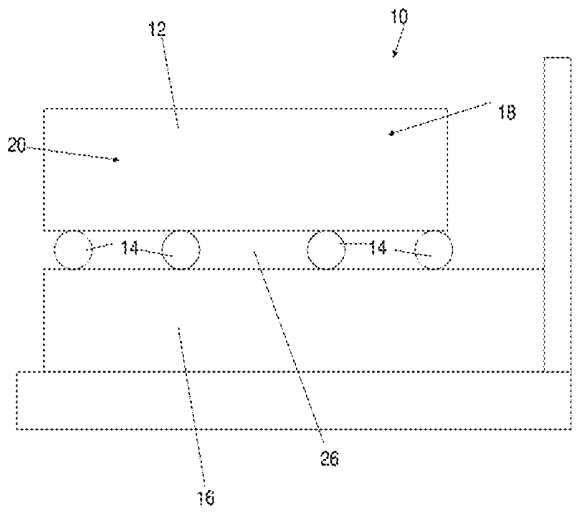
(57) **ABSTRACT**

A dual use ultrasonic transducer device for combined sensing and power transmission, comprises a first piezoelectric transducer sized for placement in a body lumen; a power unit enabling an ultrasonic power beam for tissue ablation in a tissue ablation region; and a sensing unit enabling an ultrasonic sensing beam for sensing at said tissue ablation region. In one example, a single piezoelectric surface is electrically connected to a mounting; and the mounting provides a first region of the piezoelectric surface with a first relatively high level of damping and a second region of said piezoelectric surface with a second relatively low level of damping, thereby to enable sensing from said first region and power transmission from said second region. Changes in efficiency of the transducer or the treatment during use may be inferred from changes in the impulse response or impedance or changes in the temperature of liquids that have flowed past the transducer.

25 Claims, 15 Drawing Sheets
(10 of 15 Drawing Sheet(s) Filed in Color)



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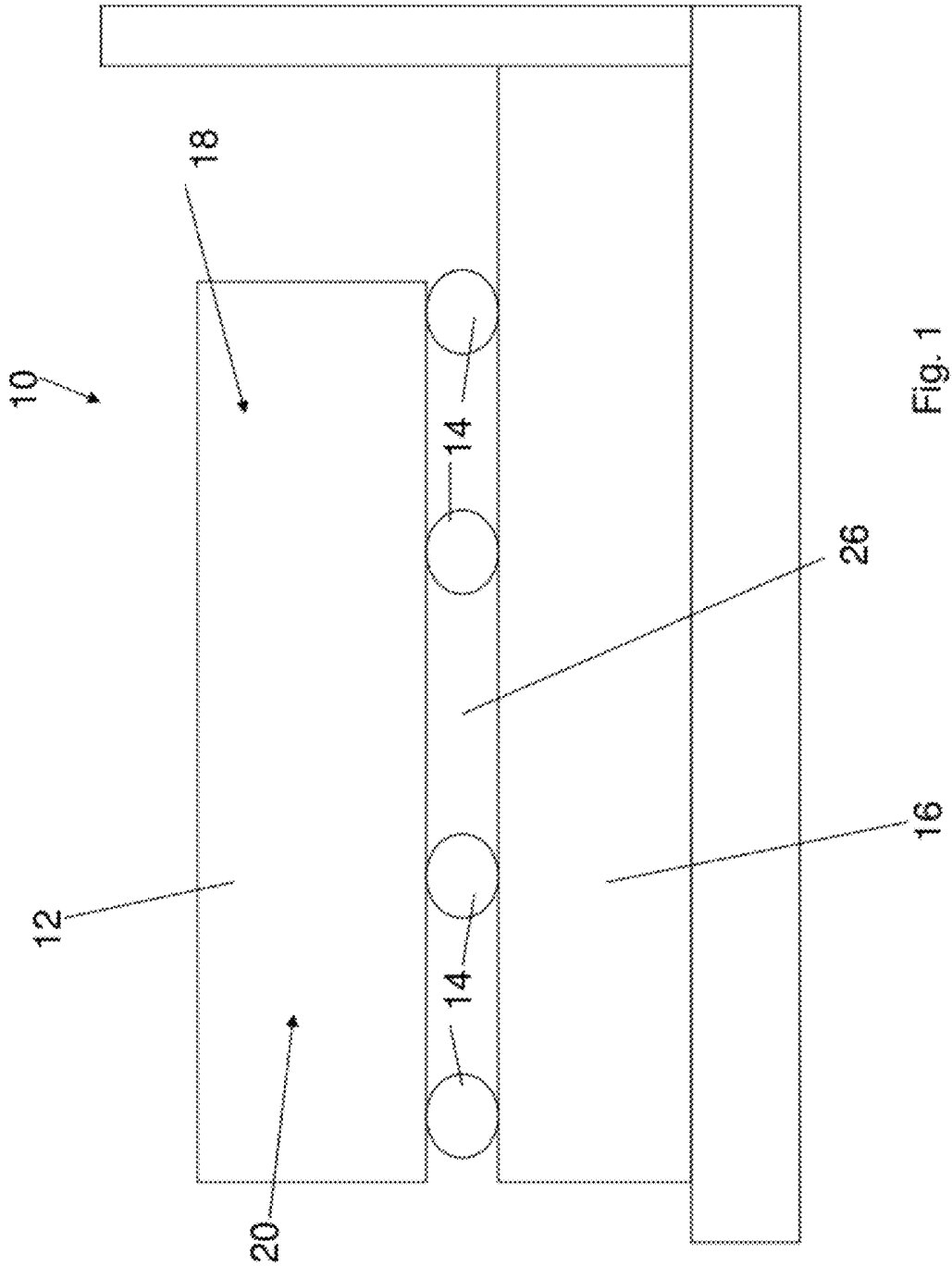

Fig. 1

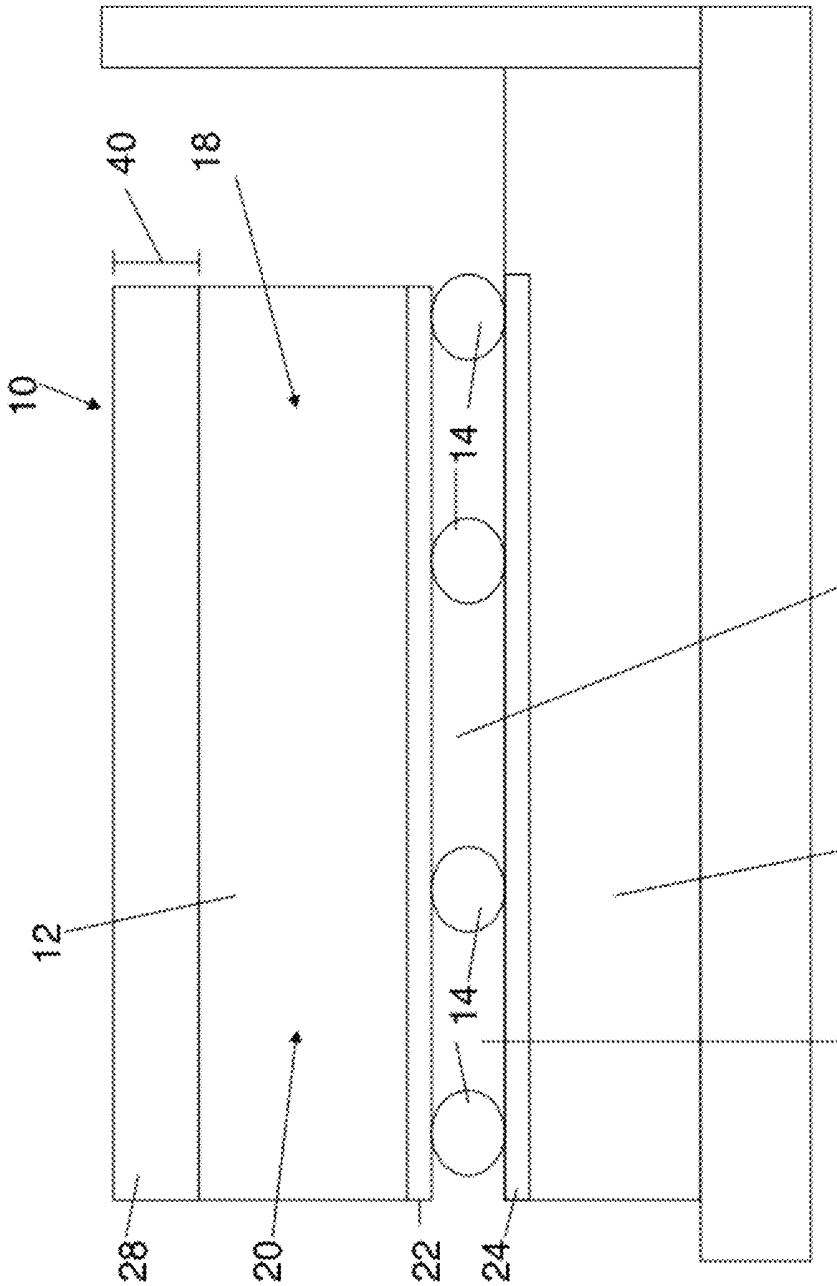

Fig. 2

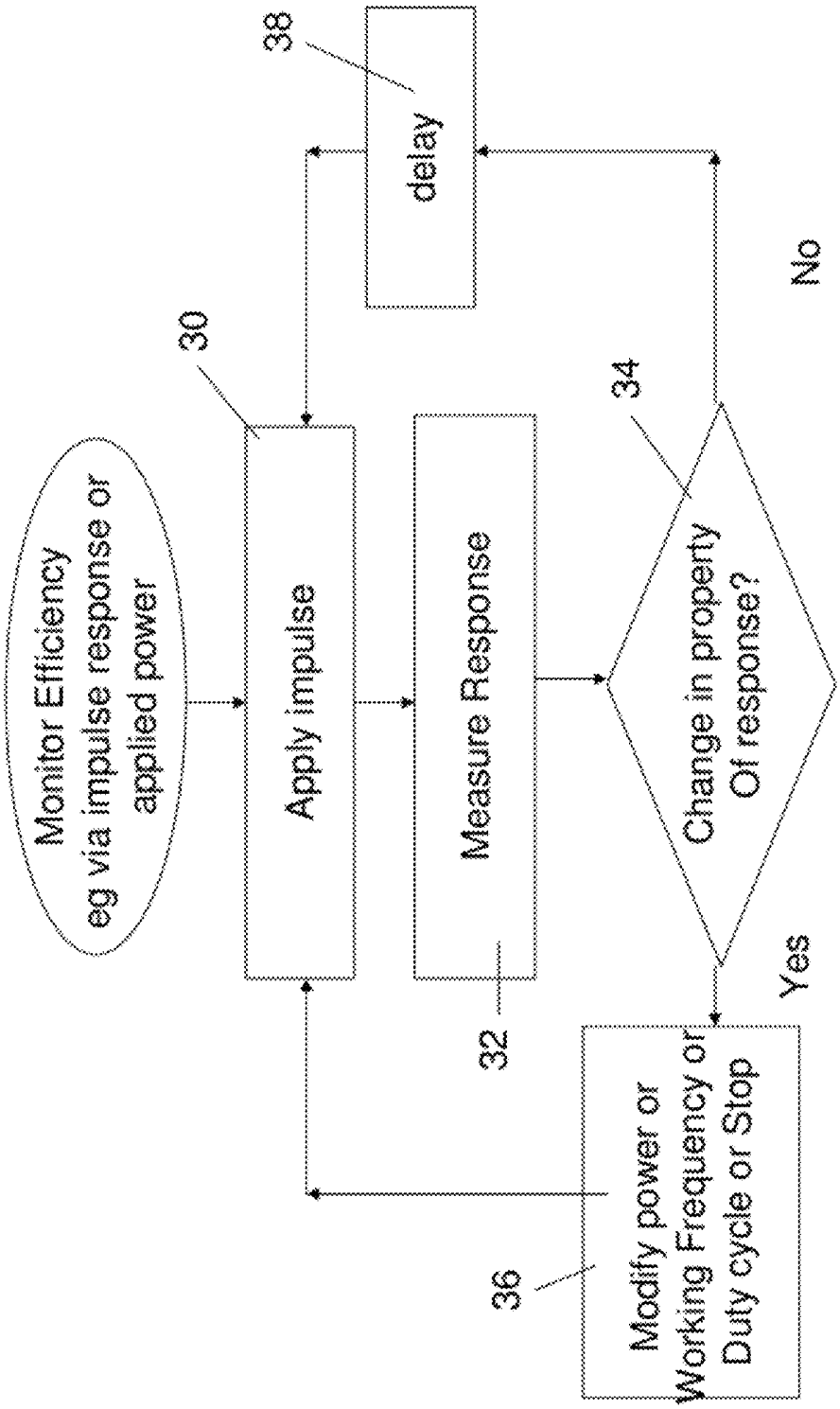
Monitor Efficiency
eg via impulse response or
applied power
Apply impulse
Measure Response
Change in property
Of response?
No
Yes
delay
Modify power or
Working Frequency or
Duty cycle or Stop
30
32
34
36
38

Fig. 3A

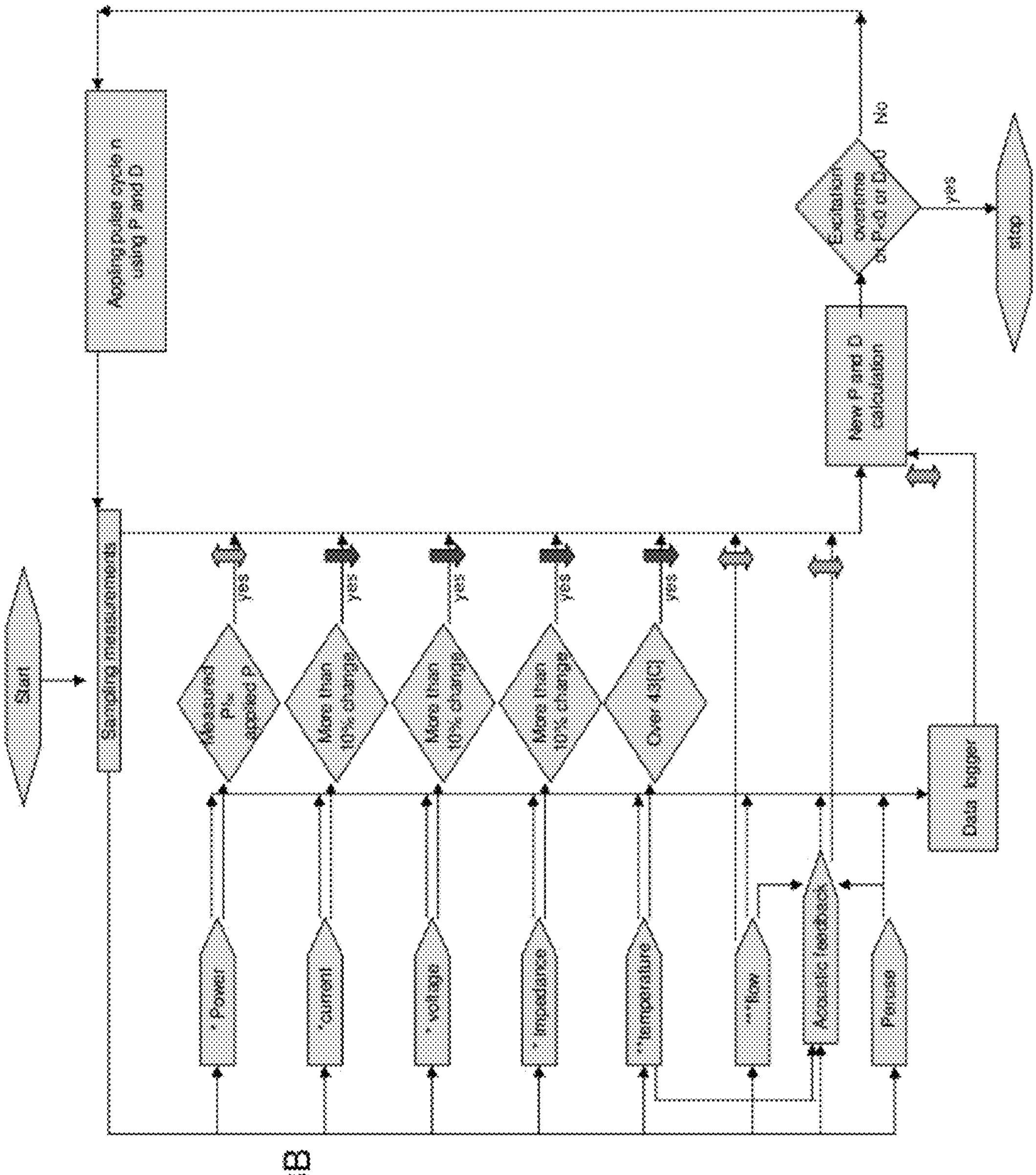
Start
Sampling measurements
Applying pulse cycle n using P and D
More than 10% change
More than 10% change
More than 10% change
Over 43[C]
yes
yes
yes
yes
yes
* Power
*current
* voltage
* impedance
**temperature
**flow
Acoustic feedback
Data logger
New P and D calculation
No
yes
stop

Fig. 3B

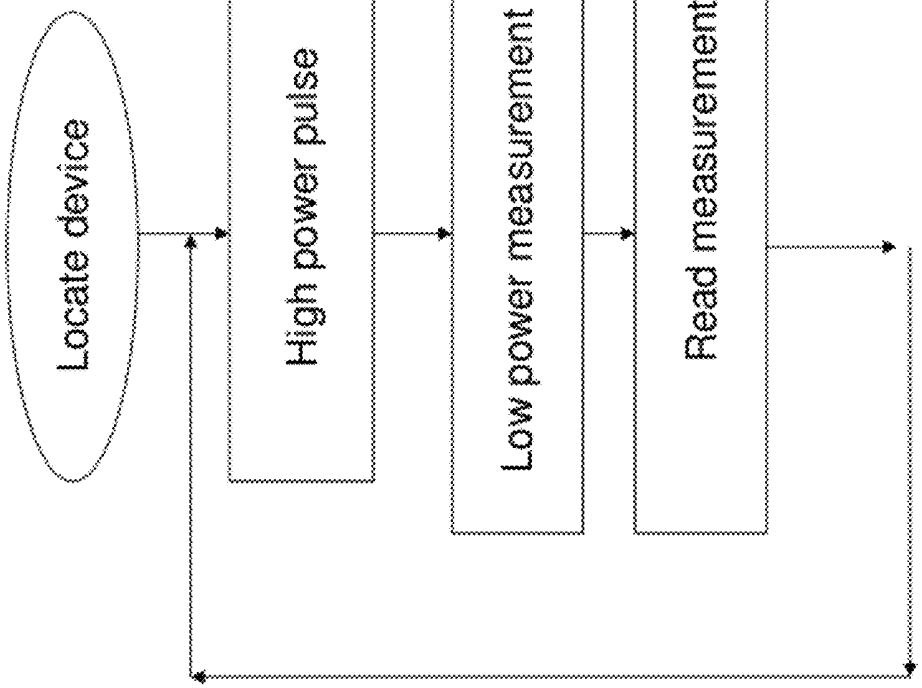
Locate device
High power pulse
Low power measurement signal
Read measurement

Fig. 4

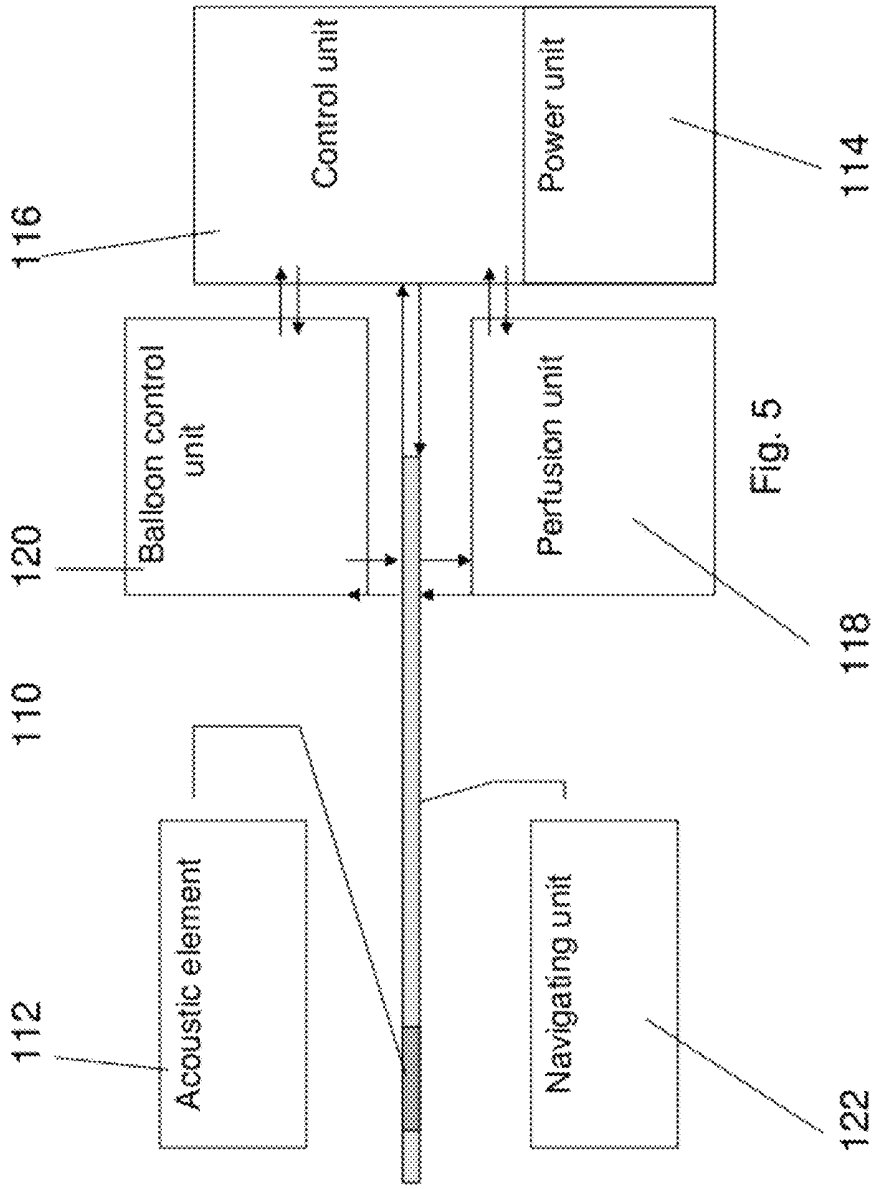
Control unit
Power unit
116
114
Balloon control unit
Perfusion unit
120
118
110
Acoustic element
Navigating unit
112
122

Fig. 5

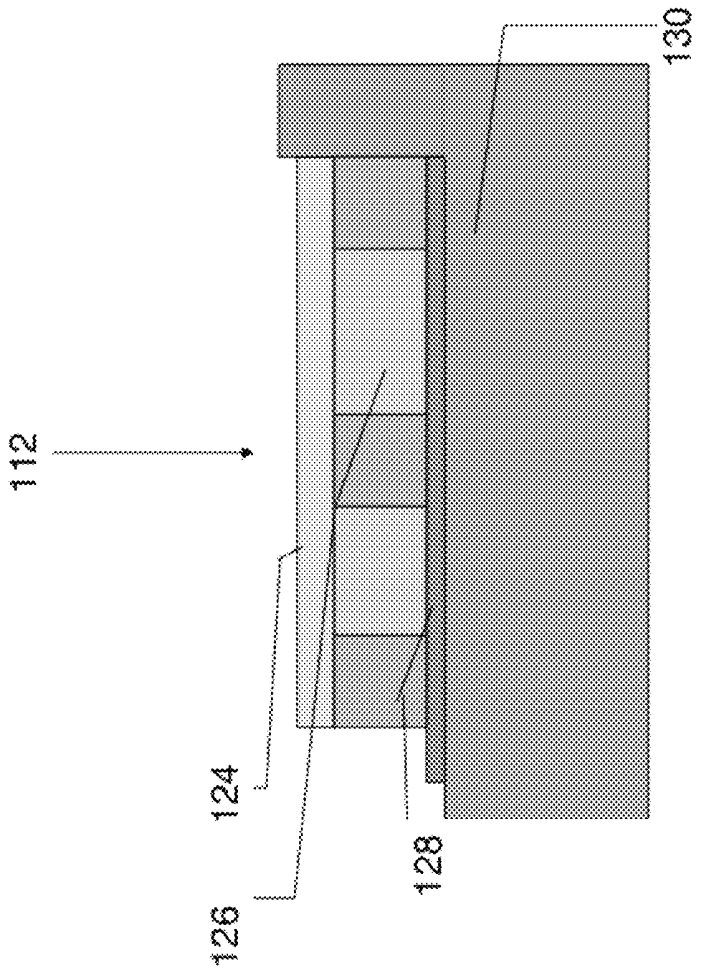

FIG. 6

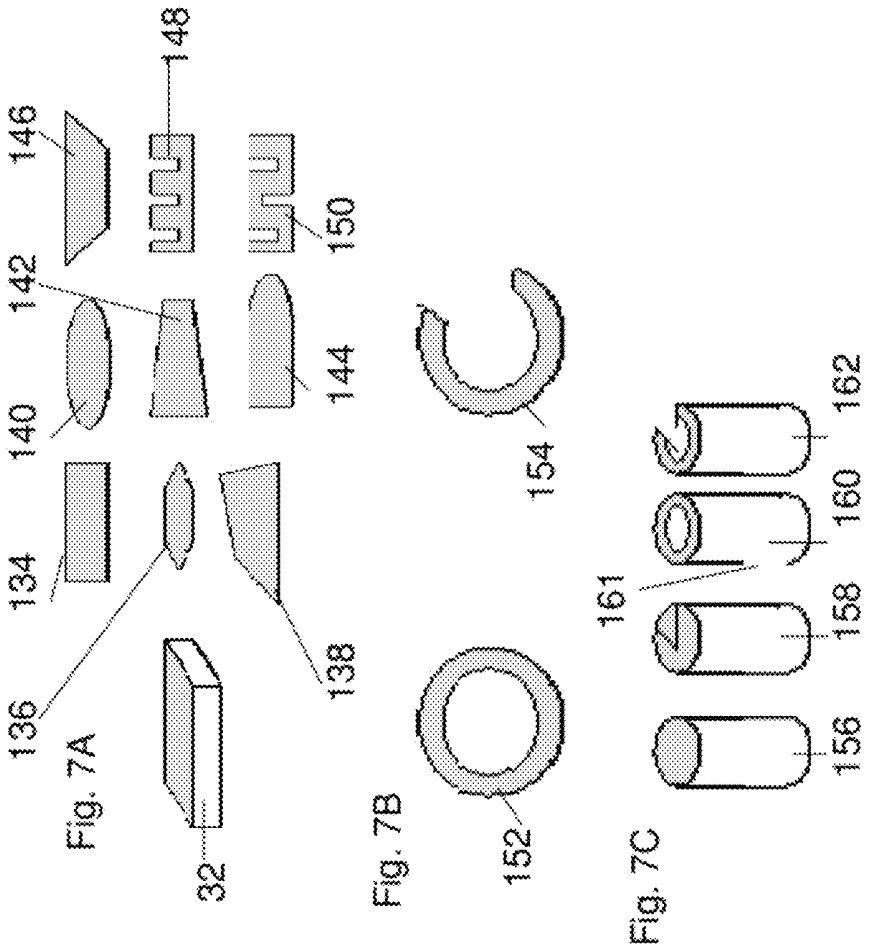

Fig. 7A

Fig. 7B

Fig. 7C

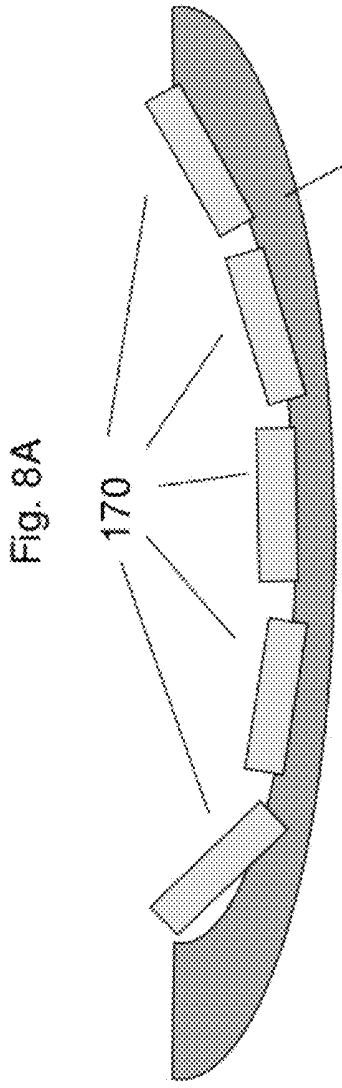

Fig. 8A

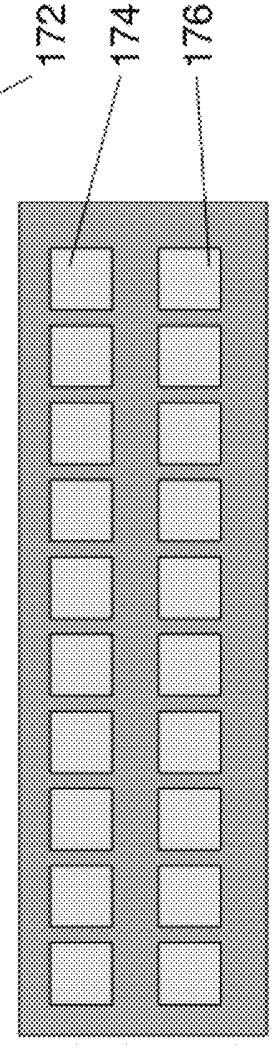

Fig. 8B

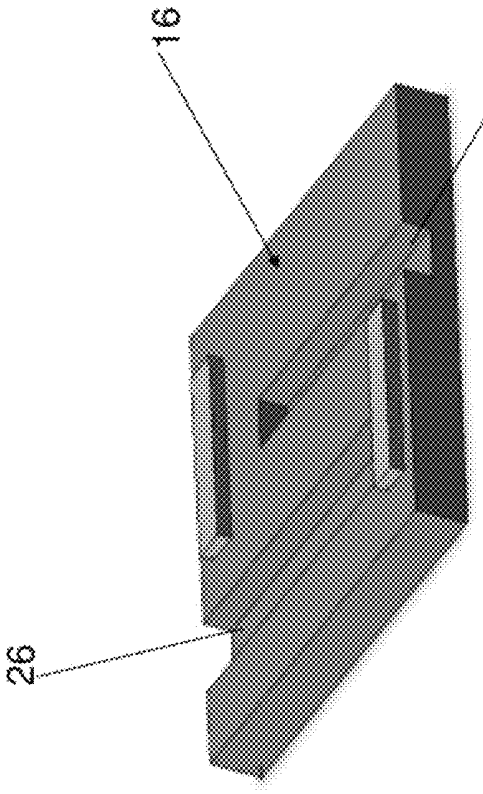

Fig. 9

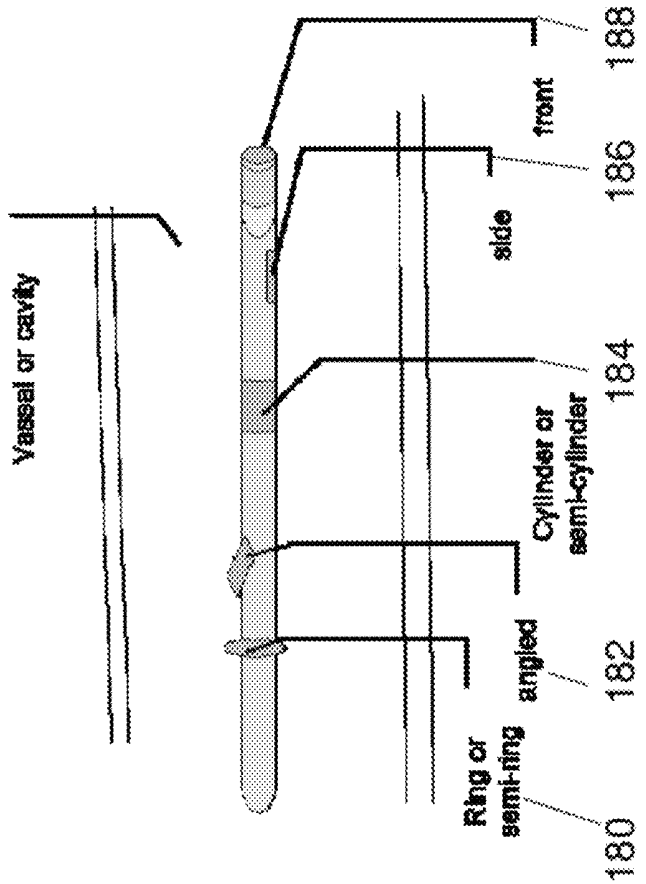
Vassal or cavity
Ring or semi-ring
angled
Cylinder or semi-cylinder
side
front
180
182
184
186
188

Fig. 10

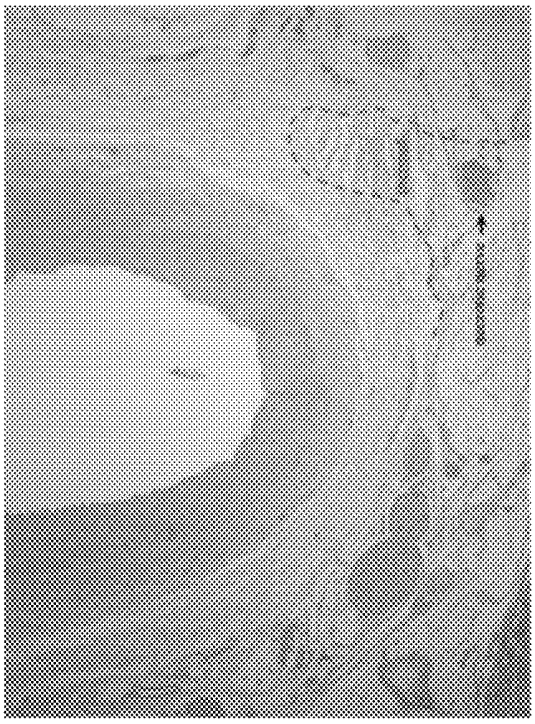

Fig. 12

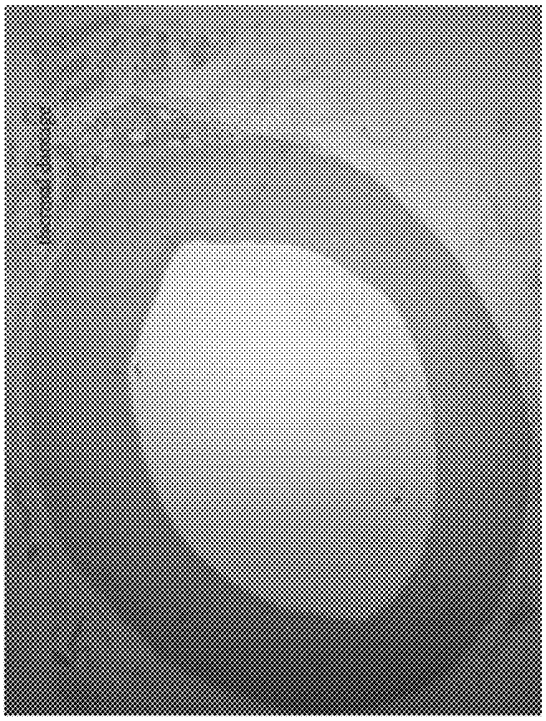

Fig. 11

Fig. 14

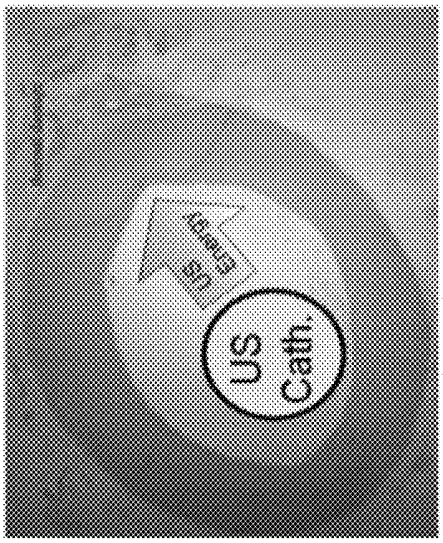

Fig. 13

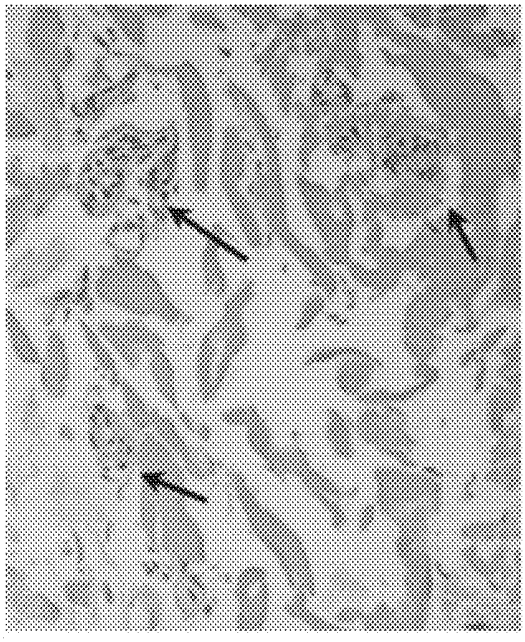

Fig. 15

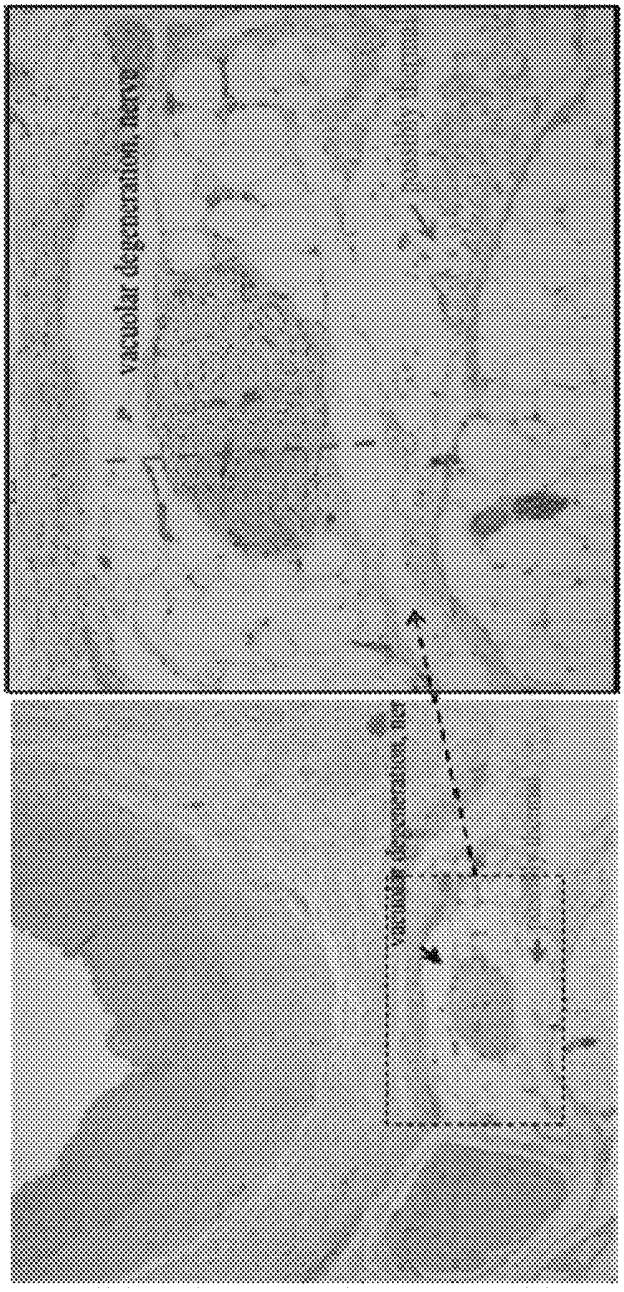

Fig. 16

ULTRASOUND TRANSDUCER AND USES THEREOF

RELATIONSHIP TO EXISTING APPLICATIONS

This application claims the benefit of priority under 35 USC 119(*e*) of U.S. Provisional Patent Application No. 61/393,947 filed Oct. 18, 2010, the contents of which are incorporated herein by reference in their entirety.

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates to an ultrasound transducer device and uses thereof and, more particularly, but not exclusively to such a transducer device modified for use in surgical procedures.

Sverdlik et al, in PCT/IL2008/000234, filed Feb. 21, 2008 disclose a method of using ultrasonic energy for surgical procedures. In a procedure for stabilizing blood vessel wall abnormality, ultrasonic heating is carried out of at least a portion of the blood vessel wall having the abnormality. A parameter is monitored relating to a property of at least a portion of the heated portion of the blood vessel wall; and heating is stopped when the monitored parameter changes by a predetermined factor or after the monitored parameter changes at a slow enough rate.

A problem arises in providing the ultrasound transducer close to the tissue that requires the procedure. It is known to put small ultrasound sensors in the blood vessels but it is difficult to ensure that the sensor is looking at the tissue that requires the procedure. A further problem involves providing the ultrasound power beam sufficiently close to the tissue requiring ablation, and controlling the beam given a) the difficulty in correctly directing the sensor and b) generally controlling factors that affect efficiency of the ablation beam.

SUMMARY OF THE INVENTION

The present embodiments may provide an transducer in which sensing and ablation are combined on a single transducer device that can be placed in a blood vessel or the like.

According to one aspect of the present invention there is provided a dual use ultrasonic transducer device for combined sensing and power transmission, the power transmission for tissue ablation, comprising:

a first piezoelectric transducer sized for placement in a body lumen;

a power unit enabling an ultrasonic power beam for tissue ablation in a tissue ablation region; and

a sensing unit enabling an ultrasonic sensing beam for sensing at said tissue ablation region.

In an embodiment, said first piezoelectric transducer comprises a piezoelectric surface, said piezoelectric surface being electrically connected to a mounting; the mounting comprising damping for said piezoelectric surface, the mounting being configured such as to provide a first region of said piezoelectric surface with a first relatively high level of damping and a second region of said piezoelectric surface with a second relatively low level of damping, thereby to enable said ultrasonic sensing beam from said first region and said power transmission beam from said second region.

An embodiment may comprise at least a second piezoelectric transducer also sized for placement in a body lumen, the first piezoelectric transducer being provided with a first, relatively high level of damping and the second piezoelectric transducer being provided with a second, relatively low, level of damping, and enabling said ultrasonic sensing beam from said first piezoelectric transducer and said ultrasonic power beam from said second piezoelectric transducer.

In an embodiment, said ultrasonic power beam and said ultrasonic sensing beam are enabled through said first piezoelectric transducer.

In an embodiment, said body lumen is a blood vessel.

An embodiment may comprise with a catheter for placing within said blood vessel.

In an embodiment, said sensing is usable in a control system to control treatment efficacy or device efficiency.

In an embodiment, said first piezoelectric transducer is configured to provide said power transmission as a non-focused beam.

In an embodiment, said first region comprises a first surface part of said piezoelectric surface and said second region comprises a second surface part of said piezoelectric surface, and a non-focused beam is provided from throughout said second surface part.

In an embodiment, said power transmission is configured to provide a thermal effect to surrounding tissues and said sensing is configured to provide imaging of said thermal effect.

In an embodiment, said thermal effect comprises denaturation of collagen and said sensing comprises detection of a change in reflected signal, or in backscatter.

An embodiment may provide said power transmission in bursts having gaps and transmit separate sensing transmissions during said gaps.

An embodiment is configured to be placed in said body lumen and said sensing region is configured to detect a lumen wall and to provide a signal to control for distance to the lumen wall and thereby ensure that the device does not touch said lumen wall.

In an embodiment, said mounting comprises an air pocket and a plurality of contact points.

In an embodiment, said mounting is provided with a surface tension sufficient to maintain said air pocket when said device is immersed in liquid.

An embodiment may comprise a matching layer for acoustic impedance matching placed on said piezoelectric surface wherein said matching layer comprises pyrolytic graphite.

The device may have a resonance and an anti-resonance, and may advantageously be used at a working frequency equal to said anti-resonance.

According to a second aspect of the present invention there is provided a method of online testing of efficiency or treatment efficacy of an ultrasound transducer to detect changes in said efficiency, said efficiency being a ratio between ultrasound energy and heat generated in said transducer, said method comprising applying an impulse to said ultrasound transducer, measuring a response of said ultrasound transducer to said impulse, and inferring changes in said efficiency or said efficacy from said measured response.

In an embodiment, said inferring said changes in efficiency comprises inferring from at least one member of the group comprising: a shape of said measured response; an envelope of said measured response, a duration of said measured response, amplitudes of said measured response, and a damping factor of said measured response.

In an embodiment, said transducer has a resonance and an anti-resonance and said online or offline testing comprises inferring a change in at least one of said resonance and said anti-resonance.

Usage of the embodiment may involve placing said transducer in a liquid-filled body lumen and carrying out said online testing while said transducer is in said body lumen.

The embodiments extend to the device when placed in a liquid within a body lumen.

According to a third aspect of the present invention there is provided a method of using an ultrasonic transducer for simultaneous heating and monitoring of a target, the method comprising providing a relatively high power ultrasonic transmission in bursts for heating said target, said bursts having gaps, and sending relatively low power ultrasonic sensing transmissions during said gaps for monitoring said target.

An embodiment may comprise using a surface of a piezoelectric sensor to produce said relatively high power and said relatively low power ultrasonic transmissions, said piezoelectric sensor surface comprising a first relatively high damping region and a second relatively low damping region, the method comprising using said first region for said monitoring and said second region for said heating.

An embodiment may comprise placing said transducer in a liquid-filled body lumen and carrying out said simultaneous heating and measuring while said transducer is in said body lumen.

An embodiment may involve testing an efficiency of said transducer or a treatment efficacy, said testing comprising applying an impulse to said transducer and measuring a response of said transducer to said impulse.

According to a fourth aspect of the present invention there is provided a method of online testing of efficiency of an ultrasound transducer to detect changes in said efficiency, said efficiency being a ratio between ultrasound energy and heat generated in said transducer, said method comprising measuring an impedance of said transducer at a current working frequency, and inferring changes in said efficiency from changes in said measured impedance.

According to a fifth aspect of the present invention there is provided a method of online testing of efficiency of an ultrasound transducer to detect changes in said efficiency, said efficiency being a ratio between ultrasound energy and heat generated in said transducer, or for testing treatment efficacy, said transducer being for placement in a liquid flow and having a temperature sensor positioned for measurement of flowing liquid downstream of said transducer, said method comprising measuring a temperature of said flowing liquid downstream of said transducer, and inferring a decrease in said efficiency or a change in said efficacy from an increase in said measured temperature.

According to a sixth aspect of the present invention there is provided a method of online testing of treatment efficacy and safety of the device of claim **1**, comprising placing the device in said lumen at a distance from a lumen wall, measuring liquid flow between the device and the wall and using changes in said flow measurement as an indicator of said treatment efficacy or said safety.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. The materials, methods, and examples provided herein are illustrative only and not intended to be limiting.

The word "exemplary" is used herein to mean "serving as an example, instance or illustration". Any embodiment described as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments and/or to exclude the incorporation of features from other embodiments.

The word "optionally" is used herein to mean "is provided in some embodiments and not provided in other embodiments". Any particular embodiment of the invention may include a plurality of "optional" features unless such features conflict.

Implementation of the method and/or system of embodiments of the invention can involve performing or completing selected tasks manually, automatically, or a combination thereof. This refers in particular to tasks involving control of the ultrasonic system.

Moreover, according to actual instrumentation and equipment of embodiments of the method and/or system of the invention, selected tasks may be implemented by hardware, by software or by firmware or by a combination thereof using an operating system.

For example, hardware for performing selected tasks according to embodiments of the invention may be implemented as a chip or a circuit. As software, selected tasks according to embodiments of the invention could be implemented as a plurality of software instructions being executed by a computer using any suitable operating system. In an exemplary embodiment of the invention, one or more tasks according to exemplary embodiments of method and/or system as described herein are performed by a data processor, such as a computing platform for executing a plurality of instructions. Optionally, the data processor includes a volatile memory for storing instructions and/or data and/or a non-volatile storage, for example, a magnetic hard-disk and/or removable media, for storing instructions and/or data. Optionally, a network connection is provided as well. A display and/or a user input device such as a keyboard or mouse are optionally provided as well.

BRIEF DESCRIPTION OF THE DRAWINGS

The patent or application file contains at least one drawing executed in color. Copies of this patent or patent application publication with color drawing(s) will be provided by the Office upon request and payment of the necessary fee.

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

In the drawings:

FIG. **1** is a simplified schematic diagram of a first embodiment of an ultrasound transducer in which sensing and ablation are combined onto a single device according to the present invention;

FIG. **2** is a simplified schematic diagram showing a modification of the transducer of FIG. **1**;

FIG. **3**A is a simplified flow chart illustrating a method for monitoring operation of an ultrasound transducer according to embodiments of the present invention;

FIG. **3**B is a flow chart showing a method of monitoring efficacy or operation of an ultrasound transducer according to further embodiments of the present invention;

FIG. **4** is a simplified flow chart illustrating a method for ablating tissue using high power pulses, and measuring during gaps in the pulse, according to embodiments of the present invention;

FIG. **5** is a simplified schematic diagram of a system using the air-backed ultrasound transducer of FIG. **1**;

FIG. **6** is a simplified schematic diagram showing a cross-section of the construction of an ultrasound transducer according to the embodiment of FIG. **1**;

FIGS. **7**A-**7**C are simplified schematic diagrams illustrating variant shapes of a piezoelectric element for the transducer of FIG. **1**;

FIG. **8**A is a side view of a series of piezoelectric elements mounted on a single mounting according to an embodiment of the present invention;

FIG. **8**B is a view from above of an arrangement of piezoelectric elements mounted in two rows according to embodiments of the present invention;

FIG. **9** is a simplified schematic diagram illustrating a construction of a PCB for mounting PCB elements that includes grooves for air bubble formation according to an embodiment of the present invention;

FIG. **10** is a simplified schematic diagram that illustrates a series of angles and positions in relation to a body vessel and a catheter, in which the transducer can be placed by navigation;

FIG. **11** is a histology slide using H&E stain, and showing the thermal effect in a pig carotid artery;

FIG. **12** is a histology slide using H&E stain, and showing the thermal effect in a pig renal artery;

FIG. **13** is a histology slide wherein analysis and marking of the thermal damage area to a pig Carotid Artery is made by a trained pathologist;

FIG. **14** is a histology slide wherein analysis and marking of the thermal damage area to a pig Renal Artery is made by a trained pathologist;

FIG. **15** is a histology slide showing analysis and marking of the blocked Vasa-Vasorum, with arrows placed by a trained pathologist in a pig Carotid Artery Vasa-Vasorum in the adventitia; and

FIG. **16** shows two histology slides with analysis and marking of the thermal damage, or nerve degeneration area, made by trained pathologist, for a pig renal artery, and nerves in adventitia.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present embodiments comprise an ultrasound transducer device and uses thereof and, more particularly, but not exclusively, such a transducer device modified for use in surgical procedures. The transducer device combines imaging and ablation into a single device.

The single device may include multiple transducers or a single transducer having multiple regions. The regions may provide respective power beams and measuring beams and methods are provided for estimating changes in efficiency while in use.

The principles and operation of an apparatus and method according to the present invention may be better understood with reference to the drawings and accompanying description.

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

Reference is now made to FIG. **1**, which is a simplified diagram showing a dual use ultrasonic transducer device **10** for combined sensing and power transmission. The transducer comprises a piezoelectric surface **12** of a piezoelectric element. The element is mounted using mounting points **14** to a printed circuit board **16**. The combination of the PCB **16** and the mounting points **14** form a mounting.

The piezoelectric element is electrically connected to the printed circuit board. For example the mounting points may be comprised of conductive glue, or may include wire connections. The piezoelectric element is vibrated in use by the electrical input to transmit a beam and also vibrates in the presence of a beam to sense ultrasound echoes. Thus the mounting comprises damping for the piezoelectric element in order to manage the vibrations. The mounting may provide different levels of damping to various parts of the piezoelectric element so as to provide different regions on the surface which are distinguished by their different levels of damping. A highly damped region is good for sensing since an acoustic beam can be transmitted and the returning echo can be reliably read by a surface whose vibrations have already died down. On the other hand power transmission benefits from the vibrations mounting up so that an undamped surface may be considered, and on the contrary, a mounting that actually multiplies vibrations would be better.

Thus the embodiment of FIG. **1** may provide the two different levels of damping to two different parts of the surface, shown as **18** for the highly damped low power sensing region and **20** for the low damping high power transmission region, so that one part is optimized for power transmission and the other part is optimized for sensing. The two regions are connected using different electrodes so that their operation is kept separate.

The low damped, high power region **20** may be configured to provide the power transmission as a non-focused beam.

The non-focused beam may be provided from throughout the surface part **20**, that is to say from throughout the body of the low damping high power region.

The power beam may provide a thermal effect to surrounding tissues, thus carrying out ablation. Different parts of the surrounding tissues may have different sensitivities to the non-focused power beam.

The sensing may provide imaging of the heating effect. Since, in the present embodiment, the surface doing the imaging is an extension of the surface providing the power beam, the sensing surface is necessarily correctly directed for sensing.

In an alternative embodiment, the same sensor surface may be used for both the power and imaging.

In a third embodiment different transducers may be placed on the device. Each transducer produces either a power beam or a measuring beam. Example configurations are shown below in FIGS. **8**A and **8**B.

The thermal effect that is used may comprise denaturation of collagen. The sensing may specifically involve detection of an increase in amplitude of the ultrasonic reflection over the transmitted beam, which increase in amplitude is an indicator of the denaturation of the collagen.

The power beam may be transmitted in bursts. The gaps in between the bursts may then be used to transmit separate sensing transmissions at lower power and allow detection without interference from the power beam.

The device is designed to be placed in a body lumen. The sensing region may detect the wall of the lumen, and this can

be used to provide a signal that can be used in a control loop to control for distance to the lumen wall. The control loop can thus be used to ensure that the device does not touch the lumen wall.

The body lumen is generally liquid. The mounting, as discussed, includes gaps **26** between the contact points **14**. The device may be designed so that gaps remain air filled even when the device is in the lumen. Thus the gaps **26** become air pockets which lie between the multiple contact points **14**.

Reference is now made to FIG. **2** which is a variation of the device of FIG. **1**.

As discussed, the air pocket may be maintained by surface tension. The mounting may be designed with a surface tension sufficient to maintain the air pocket when the device is immersed in liquid, and this may be due to the materials themselves, or, if not sufficient, then suitable coatings **22** and **24** may be applied.

In an embodiment, a matching layer **28**, for acoustic impedance matching, may be placed on the piezoelectric surface **20**. A suitable material for the matching layer is pyrolytic graphite, due to its combination of heat conducting ability and biological compatibility. Specifically pyrolytic graphite has little effect on platelets and thus does not increase the risk of clot formation.

In operation, electrical waves are applied to the acoustic surfaces **18** and **20**, which causes the surfaces to vibrate. The surfaces have resonant and anti-resonant frequencies, and the working frequency at which the device is typically operated is an anti-resonance. The anti-resonance was found empirically to provide a highest efficiency in terms of a ratio of conversion of electrical energy to sound as opposed to conversion of electrical energy to heat.

Reference is now made to FIG. **3**A, which is a simplified flow diagram illustrating a method for monitoring operation of the transducer in order to control efficiency of the device of the present embodiments, or to control efficacy of the treatment, as will be explained hereinbelow. The device efficiency may change during use, typically leading to a danger of overheating. The problem is believed to lie with materials from the blood stream, particularly clots, getting attached to the device and changing the vibration dynamics. The anti-resonant frequency changes as a result but, unless this is detected, the device continues to work at the predefined working frequency. Thus the efficiency drops and the device heats up.

To help solve the above problem the present embodiments may provide a way of online testing of efficiency of the ultrasound transducer to detect changes in its efficiency. As mentioned above, the efficiency is a ratio between ultrasound energy and heat generated in the transducer. As shown in FIG. **3**, the method involves applying an impulse to the ultrasound transducer,—box **30**, and then measuring a response of the ultrasound transducer to the impulse, as shown in box **32**. Changes in a property of the response may then be used in decision box **34** to infer changes in the efficiency of the device.

If such changes are detected then in box **36** an action is taken. The action may be stopping of the device. Alternatively it may involve changing the applied duty cycle and/or the applied power or alternatively the change may involve modifying the working frequency of the device. Subsequently, the efficiency is tested again so that the device can rapidly converge on a new efficient working frequency. If no changes are detected then a delay **38** may be introduced and the test repeated.

The test may be carried out continuously during use.

In the test, the changes in efficiency can be inferred from a change in a property of the impulse response, as shown in FIG. **3**A. However alternatives for the test include scanning the device impedance against frequency, measuring the applied power and measuring the impedance during a pulse.

In the case of the impulse test, the property may be a shape or envelope of the measured response. Alternatively the property may be a duration of the measured response, typically the time the response falls to a predetermined minimal threshold. The property may alternatively be an amplitude of the measured response, and as a further alternative the property may a damping factor, which is derived from the measured response.

As described above, the transducer device has both a resonance and an anti-resonance. Indeed the device may have several resonant frequencies and several anti-resonances formed from local maxima on the efficiency graph. The online testing may involve inferring changes in any of these maxima and minima and thus in either a resonance or an anti-resonance.

The efficiency testing is a form of test which can be carried out in situ in the liquid-filled body lumen since the impulse response can be monitored remotely via the contact points **14**.

As an alternative, the impedance of the transducer device can be tested. A fall of say ten percent in the impedance can be taken as a signal to move the working frequency or to stop the treatment.

Reference is now made to FIG. **3**B, which is a simplified diagram illustrating a more detailed control loop for the transducer device. In FIG. **3**B, changes in power, current, voltage, impedance, and temperature are used together or as alternatives and changes are looked for. In the case of current, voltage, and impedance, changes of 10 percent are looked for. In the case of temperature a measurement in excess of 43 degrees is looked for. A pulse cycle using a given power P at a duty cycle of D % is applied and over excitation leads to the device stopping. Blood flow and acoustic feedback are also obtained.

Returning now to FIG. **2**, and the ultrasonic transducer device, may have an acoustic matching layer **26** comprising pyrolytic graphite as discussed. The matching layer has a thickness **40**, which is advantageously a quarter of a wavelength of the power beam transmitted by the ultrasonic transducer. As mentioned the working frequency could be the anti-resonance of the device so that the thickness **40** is a quarter of a wavelength of the working frequency.

Reference is now made to FIG. **4**, which illustrates a method of using an ultrasonic transducer of the present embodiments for simultaneous heating and monitoring of a target. The method comprises a box **50** for providing a relatively high power ultrasonic transmission in bursts for heating the target. The bursts have gaps, as discussed above, and the method uses the gaps to send relatively low power ultrasonic sensing transmissions—box **52**—for monitoring the target. The measurements are then read—box **54**. As discussed, the high power and low power beams may be provided from different parts of the same surface of a piezoelectric sensor which are differentially damped, at working frequencies which are anti-resonances of the transducer. Alternatively they may be provided from the same surface. Alternatively high power and low power beams may be provided from different transducers on the device.

The present embodiments are now considered in greater detail. The present embodiments relate generally to devices, parameters and methods for the treatment of tissue using ultrasonic waves in particular for heating, at a target area such

as in the wall of a tube or cavity, located in the living body, The treatment may involve excitation using high power acoustic energy.

The ultrasonic effect is achieved in such a way that there is control over the heated target tissue volume and location. Preferably, a controlled volume of tissue between the ultrasonic element and the target tissue, is not treated. This distal effect may be achieved without the need of mechanical contact with the cavity walls.

Detailed application of the above includes the ability to cause moderate thermal damage within a controlled volume at the outer side of a cavity wall without damaging the inner side of the vessel, the inner side including different types of epithelium.

The treatment method may be applied by creating a gradient of different temperatures in the tissue by the combined effects of: heating the tissue with high power ultrasound and cooling of the tissue using conduction and convection. The convection could be of natural fluid, for example blood flow, or by artificial injection of cooling liquid, for example cold saline injection. Additional temperature effects that are widely elaborated in other sources may also simultaneously influence the temperature gradient, for example—capillary blood perfusion.

The heating control is performed by controlling the parameters of the ultrasonic field and the transmission protocol, including: transmission frequency, power, duration and duty cycle, as will be described in greater detail herein.

The treatment is controlled by feedback from the tissue using an echo received from the tissue during the treatment. Specifically, at high temperatures above 55° C. an irreversible change is created in the collagen fibers in the tissue; this change may be monitored using the ultrasonic echo from the tissue, which allows mapping of the damaged tissue area.

It is also possible to increase or\and to add effects by ejection of fluids into the treated area or at an upstream area in such a way that the ejected fluid is inserted into the vessel, typically through the vasa-vasorum or the adventitia lymph capillary.

Nevertheless, it is possible to control the flow in the vessel at different locations using different devices, for example a balloon opening in the vessel and again changing the treated effects in the tissue.

Typically, the ultrasonic transmission is applied at high power, high frequency and for more than one second. Heating of the tissue in the ultrasonic field is performed by absorption of the acoustic energy in a process of dissipation of mechanical energy. The absorption and influence of the energy on the tissue includes inter alia the following effects: a heating effect, a mechanical effect, a pressure effect, a sub-pressure and a cavitation effect.

Simultaneously with the transmission the cooling effect is achieved by liquid flow in the vessel or fluid present (for example urine, lymphatic liquid, bile) or liquid active ejection.

The present embodiments may provide the possibility of transmitting the energy without touching the cavity all. By not touching it is possible to increase protection for both the elements and the non target tissue by allowing fluid to flow on the cavity walls and on the transducer surface. The liquid provides for cooling. The present embodiments may also allow for easier operation by not restricting the transducer location.

The present embodiments may transmit a non-focused acoustic field to reach the target tissue. An advantage of not having to focus the field is that there is no need to control the tissue distance from the transducer. For example renal denervation may be carried out simply by allowing the catheter to transmit a wide, high power acoustic field from a nonspecific location in the artery to a distal nonspecific location of the renal nerve.

Embodiments of the invention may allow ejection of materials into the treated area or to an upstream area therefrom in a way that the materials are inserted into the vessel, say through the vasa-vasorum or the adventitia lymph capillary.

The embodiments described herein allow sampling of the voltage created on the ultrasonic element due to echoes from the tissue and processing the data in such a way that the treated tissue is monitored.

Echo sampling and recording and or processing for measurement and monitoring can be performed simultaneously with the treatment. Such simultaneous treatment and analysis can increase the level of control of the treatment in real time and help ensure achievement of the desired results.

More specifically, the following information may be monitored from the echoes received within a vessel:

wall distance from the transducer,

vessel layer (media, adventitia, peri-adventitia) position,

thermal effect in the tissue location and

area of the thermal effect.

The data analysis method may include echo intensity, backscatter, spectral signature mapping, elastography, classification according to classification matrix of tissues, and the ultrasonic effect.

The control unit may use the above data and analysis for increasing the treatment, or reducing the treatment, or stopping the treatment, or providing indications regarding the treatment stage, or providing indications to stop or to continue the treatment.

A therapeutic catheter with an ultrasonic transducer may allow for transmission to the vessel from the inner side.

An ultrasonic transducer may be placed on the skin, with an internal catheter and transmission to the outer side of the cavity.

An endoscope system may include an ultrasonic element in its tip. The endoscope may be inserted through the skin and ultrasonic transmission may be provided to the outer side of the cavity.

The fluid control methods may include one or more of the following implementations:

A restrictor around the transducer. The implementation may involve: placing the transducer at a different location in the vessel, and controlling the flow;

A restrictor near the transducer. The implementation may again involve placing the transducer at a different location in the vessel, and controlling the flow;

A restrictor in front of (upstream of) the transducer. The method may involve blocking the flow upstream in order to load the vasa-vasorum with liquid and particles.

A restrictor past, that is downstream of, the transducer. The method may involve blocking the flow downstream of the transducer to allow drug delivery specifically to the treated area;

The restrictor may be one or more of the following: a balloon, a wire, nets, or a thin plastic sheet.

Manipulation of in the tissue reaction to the ultrasonic treatment is possible by:

Injecting vasoconstriction materials into the blood, and in this way reducing the perfusion and heat evacuation from the tissue, or injecting or evoking micro-bubbles and increasing the heating by increasing absorption of the ultrasonic energy, or the evoked micro-bubbles may be produced by use of an additional separate transducer.

Micro-bubble transportation through the cell membrane may be increased using the acoustic treatment, and may achieve a multiplied effect.

The tissue may be cooled before treatment in order to protect and or control the treated area and non-treated area.

Artificial opening of a minimal cavity surgery opening in the skin for insertion of the therapeutic catheter may be provided.

The ultrasonic field and/or the level of perfusion can be controlled and manipulated by influencing the body system in general.

Possible target tissues for the device include one or more of the following and their nearby tissues to douse cavities: arteries, veins, lymph vessels, intestine, esophagus, CNS, urine lumen, gall lumen, Stomach, and Tear Trough.

Applications for the above-described embodiments include the following:

Blood vessel wall pathology. For example for an atherosclerotic lesion;

Healthy blood vessel wall treatment;

Treatment of tissue near the blood vessel wall, for example renal denervation;

Treatment of tissue near the urine lumen wall, for example prostate treatment;

Treatment of tissue far from the urine lumen wall, for example prostate cancer.

More detailed examples for treatment and advantages using the present embodiments include phantom pain treatment in which, the target tissue is nerve tissue in the limbs. The catheter cavity may be located in a limb artery. The purpose of the treatment may be reducing phantom pain innervations by denerving the injured nerve.

A point to note is that the attenuation of the ultrasound field is smaller in the fatty tissue around the nerves than in the nerves themselves at the device frequencies. Furthermore the fatty tissue, due to its low heat conduction, isolates the heat created in the nerves. Such phenomena increase the selectiveness of the treatment.

An additional example of treatment is renal denervation.

In this treatment the target is the renal nerves. The catheter cavity is located in the renal artery. The purpose is to reduce pressure on the heart for high blood pressure patients. It is noted that the frequency, power and acoustic beam as per the data and results hereinbelow, treat the nerves without or with minimal damage to the artery. In addition, as in the previous example, the attenuation is smaller in the fatty tissue around the nerves than in the nerves themselves at the device frequencies, which increases the selectiveness of the treatment.

Possible treatment effects in the tissues can be one or more of the following:

Cell necrosis occurring in one or more of: lymphocytes, macrophages, smooth muscle cells, fibroblasts, endothelial cells, and neurons;

Reduced change in the tissue activity including: reducing smooth muscle function, reducing or blocking nerve activity, reducing or blocking the generation of the heart beat potential to the heart muscles;

Mechanical blocking of the vasa-vasorum or\ and the lymph capillary;

Mechanical changes in the collagen fibers, an increase or decrease in stiffness and reducing the maximal tension for tearing;

Biochemical changing in the tissues may include: reducing or preventing plate connection to collagen, and changes of material diffusion through the cell walls.

The device may be operated using typical parameters for acoustic transmission as follows:

Transmission frequency: 5-30 MHz;

imaging frequency 5-60 MHz;

Transmission intensity (SATA): up to 200 w/cm^2;

Transmission duration (total time): 1-120 seconds.

Reference is now made to FIG. **5**, which is a simplified block diagram of a system according to an embodiment of the present invention. In FIG. **5**, the system **110** may contain one or more of an acoustic transducer **112**, a power supply unit **114**, a control unit **116**, a pumping or circulation unit, shown as perfusion unit **118**, a balloon control unit **120**, and a navigating shaft **122**.

The navigating unit allows the acoustic element to navigate to the location or locations at which it is needed. The balloon control unit controls a balloon for supporting the lumen as needed. The perfusion unit provides injection substances as necessary.

Reference is now made to FIG. **6**, which is a schematic illustration of the acoustic element **112** of FIG. **1**. The acoustic element **112**, typically an ultrasonic element, includes a piezoelectric element **124** which converts electrical energy into an acoustic beam. The piezoelectric element is mounted on PCB board **126**, for example via air gap **128**. The PCB in turn is mounted on housing **130** which protects the acoustic element.

The ultrasonic elements transfer the energy to the target tissue, and may also be used as sensors for receiving reflections from the tissue.

The ultrasonic element may also be used as a jet evacuator of fluids for cooling or/and for drug delivery.

The ultrasonic element can be used as a microbubble evacuator.

The ultrasonic element typically includes one or more ultrasonic transducers including a piezoelectric material **24** or a MEMS element.

Electrodes may provide power to the transducer. The housing **30** protects the assembly, and an electrical connection may be provided between the electrodes and the catheter wires.

The transducer element **124** may, as mentioned by a piezoelectric elements or a MEMS element.

A PIEZO-electric transducer element may typically be made from PIEZO-electric material, for example: PZT ceramics, PIEZO-electric quartz.

Reference is now made to FIGS. **7**A, **7**B and **7**C which illustrate designs for the ultrasonic element **112**. FIG. **7**A illustrates a series of shapes where the depth cross-section is rectangular as shown in element **132**. The remaining elements in FIG. **7**A are viewed from above. Element **134** is rectangular as seen from above. Element **136** is a hexagon. Element **138** is an irregular quadrilateral. Element **140** is a flattened circle. Element **142** is a trapezium. Element **144** is a bullet shape. Element **146** is a trapezium having a shorter dimension between its parallel sides than the trapezium of element **142**. Element **148** is a comb shape having a narrow tooth at a first end followed by three wider teeth. Element **150** is a "W" shape, again with a narrow tooth projection at a first end.

FIG. **7**B illustrates a closed ring shaped element **152** and an open ring shaped element **154**.

FIG. **7**C illustrates four variations on a cylindrical element. Element **156** is a filled cylinder. Element **58** is a cylinder with a removable sector. Element **160** is a hollow cylinder having an opening **161** in the lower wall, and element **162** is a hollow cylinder having an open part of the cylinder wall along its length.

In addition the element **112** may be spherical.

In embodiments the transducer described above does not necessarily include a focal point for the ultrasonic beam. As a

result the beam can reach various targets without requiring a precise distance between the element and the target, as will be described in greater detail below.

Possible construction of the transducer may comprise regular coating methods for piezo elements, and coating materials including one or more of: silver, Ni, gold, copper, or carbon nano-tubes.

Additional coating of the electrodes may improve one or more of the following: the electric conductivity, the acoustic matching, the acoustic reflection or the acoustic amplification.

The additional coating may use any of a variety of materials including polymers, glass and metals.

The PIEZO-electric material may for example comprise: PIEZO-electric ceramics and/or PIEZO-electric quartz. An embodiment as discussed hereinbelow with cooling methods may allow the design to use high hardness ceramics, which have advantages of being of high efficiency, and being small and cheap.

MEMS—the acoustic element can also be implemented using MEMS.

More than one acoustic element can be implemented, for example:

a phased array matrix of elements;

a non-linear geometric array;

a matrix of elements each having different resonant frequencies

Reference is now made to FIGS. **8**A and **8**B which illustrate examples for multi-elements transducers. FIG. **8**A is a side view showing five piezoelectric elements **170** mounted on a curved PCB **172**. FIG. **8**B is a view from above showing two rows of piezoelectric elements **174** and **176**.

The housing **130** can made from one or more of the following materials: metals, ceramics, PZT, PIEZO-electric ceramics, glass, polymers or carbons.

The housing may provide an angiogram directional projection for better placing of the element. The housing may further be shaped to provide focusing or to affect fluid flow within the lumen around the element.

The housing may be designed to provide relatively high heat transfer from the element in order to avoid overheating. Typically the heat conductance is a function of shape and of the material used, however standard cooling fins cannot be used in the blood stream as they may cause platelets to break, thus causing blood clots.

The housing can include acoustic damping materials, such as tungsten, or alternatively may be designed to provide an acoustic amplifying effect. As per the discussion above, typically some of the piezoelectric surface is damped and some is provided with acoustic amplification.

A drug delivery capsule may be provided to inject materials into the bloodstream as required by the procedure.

Reference is now made to FIG. **9**, which illustrates an embodiment of a printed circuit board **16** for mounting of the acoustic transducer **12**. The printed circuit board may include different thickness to provide the gaps for the air pockets referred to above.

The printed circuit may comprise materials such as hard polymers, flexible polymers, glass-fiber and carbon fiber. Alternatively, the printed circuit may be printed directly on the housing.

As discussed, connection to the acoustic element may use any of wire soldering, paste soldering process, conductive gluing and wire bonding. The connection is preferably both a good heat conductor and a good electrical conductor.

The circuit itself may include vias of copper or other metals for higher heat transfer. One or more printed materials may be provided on the board, including: copper, metals, polymers, and intermediate materials.

Coatings such as metals, PZT, chemical coatings, isolation coatings, hydrophilic coatings and hydrophobic coatings may be used on different parts of the PCB or housing.

The acoustic transducer may be connected to the control unit **116** using different kinds of wires including: coax wire, twisted pair, and fiber optic cable.

The acoustic transducer and the catheter may be coated with different coatings including: an isolation coating, a praline, NiSi, hydrophobic coating, hydrophilic coating, or any kind of biocompatible coating,

As mentioned above, an air pocket may be maintained between the PCB and the piezoelectric element.

The acoustic isolation of the piezoelectric element and consequent increase in efficiency has been mentioned above. This advantage can be used for working in small cavities in order to improve the ability to heat the target volume without at the same time heating the transducer volume.

Air pockets may be formed by the use of trenches in the PCB structure as illustrated with reference to FIG. **9**. or by providing a mounting as shown in FIG. **1** where a gap is defined between the ultrasonic element and the PCB.

Hydrophobic coatings, including praline, may be used to enhance the surface tension effect in order to prevent the water medium from penetrating into the air volume, as mentioned in respect of FIG. **2**.

The coating may cover the entire air bubble surrounding or part of it and prevent water from penetrating in.

It is noted that the air bubble does not need to be maintained indefinitely. It is sufficient that it is retained for the duration of the ultrasound procedure.

The ultrasonic element may use different anti-resonance values for the working frequency when available. For example one anti-resonance may be used for moderate heating of the tissue, another for power heating of the tissue and yet another for monitoring.

The device may be able to provide an injection jet to the tissue, may provide for increasing fluid flow under the element, say to improve cooling, may evoke micro-bubbles, and may monitor the heating effect and or any injection. The measurement system may include doppler analysis and the heat treatment may use focused or unfocused ultrasound.

In embodiments, the navigation unit **122** may allow the acoustic element to reach the desired location. The navigation unit may further have some auxiliary functions. For example it may deliver the power to the element from the control unit, record measurements from the element and even deliver the measurements to the control unit **116**. The navigation unit may further be involved in heat absorption or transfer from the transducer to the ambient or to the surrounding liquids by providing an additional heat exchange surface extending from the catheter.

The navigation unit may also mechanically hold and place the ultrasonic elements in different locations and at different desired angles, as per FIG. **10**. In FIG. **10** a ring configuration **180** may be used, or an angle configuration **182**, or a cylindrical configuration **184** or a side configuration **186** or a front configuration **188**, each in relation to the catheter.

In embodiments, the navigation unit may include an external navigated control unit. Close to the ultrasonic element, a placing unit may include a balloon, a placing wire or a net or the like.

A heat sink function may including cooling the ultrasonic unit using outside fluid including: blood, urine or CSF. The

function may include increasing the heat evacuation by pumping fluid over or from the acoustic unit surface. The function may involve increasing the heat evacuation using internal or external heat conductive material, including: blood passivation coating, or printed coating, or may include increasing the heat evacuation using an internal or external heat conductive balloon.

Heat evacuation may be increased by using an internal or external heat conductive balloon with heat conduction material.

The control unit **116** may provide various kinds of closed loop control and indications on the treatments. The control unit may receive signals from echoes from the tissue. The echo may indicate the area and treatment effect, or the echo can indicate the distance from the cavity wall to the transducer device. The sensor may be a temperature sensor, which may indirectly sense the temperature of the transducer by measuring fluid that has just passed the sensor. The temperature may indicate the treatment efficiency, or efficiency of cooling of the cavity, or the cooling or heating of the transducer.

A power sensor can indicate the output treatment energy. A blood pressure sensor or other like sensors may be provided to indicate reaction to the treatment. A flow sensor can monitor fluid flow in the region of the treatment.

Closed loop effects which do not require the control unit may also be used, as known to the skilled person, for example a coating material on the transducer surface may be provided that attaches to particles or other materials that come from the treated tissue. The attachment may be used to control the ultrasonic process by making changes to the transducer frequency during operation.

Materials that can be inserted into the target tissue volume include restenosis prevention materials, for treatment of blood vessels, and materials that are used in drug eluting stents, such as sirolimus, and paclitaxel.

Other materials can be used, say in drug exuding balloons, and may include materials that are used for bio-degradable stents, anti-Inflammatory materials, medications that may be better presented locally to the tissue than systemically, anti-thrombotic materials, such as Heparin, Aspirin, Ticlopidine, and Clopidogrel, and materials that can cause damage or death to target tissues. Thus materials that can cause nerve death may be supplied for renal denervation.

Also, materials that may help in blocking of the tissue micro-circulation in heating, such as polymers that undergo cross linking, or soluble collagen, or material that may increase the ultrasonic heating of the tissue, such as micro-bubbles that cause higher energy absorption, may be used, or in the latter case generated on site. Micro-bubble transportation through the cells membrane can be increased using the acoustic treatment, and achieve a multiplicative effect. Also any kind of medication can be applied.

The transducer may be positioned on a catheter inside blood-vessels or blood cavities. Ultrasonic irradiation of the target tissue from inside the vessel lumen or cavity outwards may then be provided. Cooling of the piezoelectric element may be achieved by making the design sufficiently conductive and then using blood flow or flow of a fluid from an external source, such as saline that is irrigated into the blood vessel.

The transducer may be positioned on a catheter inside tissue canals or cavities of body fluids in the body, such as the urethra or urinary bladder, or in the spinal cord or brain ventricles (CNS fluid). Ultrasonic irradiation of the target tissue from inside the canal/cavity outwards may then be provided.

The transducer may alternatively be positioned on the tip of an endoscope or like device. The endoscope is inserted through a small hole in the skin, and the ultrasonic transducer is positioned on or near the target tissue.

For cooling, external irrigation is allowed to flow into the area of the treatment cavity. The endoscope tip may for example be positioned inside a balloon like device. The cooling fluid flows inside the balloon. The balloon is positioned next to the treatment tissue location. The ultrasonic transducer irradiates the target tissue through the balloon wall. Alternatively, the balloon may be positioned on the skin and not inserted through it. The treatment target may be near the skin.

The ultrasonic transducer may be positioned at a location that allows ultrasonic irradiation of the target tissue. Irrigation of required material in a liquid form may be provided into the blood vessels or lymphatic vessels that supply the perfusion or lymphatic capillaries of the target tissue volume, for example the artery vasa-vasorum.

The method may involve waiting a known time constant for the required material to reach the target tissue.

It is possible to add micro-bubbles to the fluid material in order to help with detection of presence of the material in the target tissue. Micro-bubbles may be detected using ultrasound and sub-harmonic imaging. Micro-bubbles may also improve heating of the target tissue under ultrasonic energy, due to higher absorption of the ultrasonic energy in the tissue volume where they are located.

Applying a thermal effect in the tissue may cause the capillaries to be blocked mechanically or by blood coagulation.

Ultrasound energy applies mechanical force on particles that are present in a liquid, when there is a difference in the acoustic impedance, which is a function of the density multiplied by the speed of sound, between the particles and the liquid. The applied force then pushes particles along the direction of the traveling ultrasonic waves. The mechanical force phenomenon can be used to ensure that required substances arrive at the treatment site.

The ultrasonic transducer may be positioned in a tissue liquid cavity such as a blood vessel, near the target tissue, while ensuring a liquid spacing between the target tissue and the ultrasonic transducer irradiating face. As mentioned above a control loop can be used to ensure that the transducer does not touch the vessel wall and damage epithelium cells.

The required material may be released into the tissue liquid cavity in a way that will cause some of the particles to enter the spacing between the target tissue and the ultrasonic transducer irradiating face. One way of doing this is to coat the face of the ultrasonic transducer with the required material, such that the operation of the ultrasonic transducer may cause particles of the required material to be released into the surrounding liquid.

Another possibility is to add micro-bubbles to the required material fluid in order to detect the material presence in the target tissue. Micro-bubbles may be detected using ultrasound and sub-harmonic imaging.

Yet another possibility is to activate the ultrasonic transducer so as to apply force on the required material particles to push the particles into the blood vessel wall near the ultrasonic transducer irradiating face, using the pushing effect mentioned above.

Another possibility is to apply the ultrasonic energy in short high power pulses with long separations between each pulse. This may apply mechanical force, as per the phenomenon discussed above, to the particles to push them into the tissue wall, without heating the tissue wall extensively.

A further possibility is that activation of the captured required material can be achieved by applying additional ultrasonic energy or some other kind of external energy such as a magnetic field on Ferro-electric particles, or an ultrasonic shock-wave to the particles

The present embodiments may be used for the treatment of renal denervation. The transducer is simply positioned at 1, 2 or more treatment points, and there is no need for tip manipulation or accurate positioning. The total energizing duration may be between two seconds and two minutes. Real-time feedback of treatment progress may be provided. The advantages of ultrasonic treatment include directional, localized and remote target tissue effects with minimal damage to other closer tissues, possibly reducing pain, preservation of endothelium and elastic lamina structure and function, sot that there is no post treatment stenosis, or at least reduced post treatment stenosis, the avoidance of any mechanical contact on the blood vessel wall, and overall a more robust treatment effect due to real-time feedback.

The following table is a summary of currently contemplated clinical applications.

TABLE 1

Currently Contemplated Clinical Applications

#	Application Name	Anatomy	Target
1.	Renal sympathetic nerve modulation	Renal artery	Renal sympathetic nerves
2.	Carotid sympathetic nerve modulation	Carotid artery	Carotid sympathetic nerves
3.	Vagus sympathetic nerve modulation	Aorta	Vagus sympathetic nerve
4.	Peripheral sympathetic nerve modulation	Peripheral blood vessels	Peripheral sympathetic nerves
5.	Pain nerve modulation	Spinal cord cannel	Pain nerves
6.	Restenosis decrease	All relevant arteries	Artery media and adventitia
7.	Vulnerable plaque stabilization	All relevant arteries	Artery media and adventitia
8.	Atherosclerosis passivation	All relevant arteries	Artery media and adventitia
9.	Plaque volume decrease	All relevant arteries	Artery media and adventitia
10.	Plaque thrombosis decrease	All relevant arteries	Artery media and adventitia
11.	Tetanic limb muscle tonus decrease	Limb arteries or veins	Peripheral motor nerves
12.	Atrial fibrillation prevention	Right atria	Pulmonary vain insertion
13.	Cardiac arrhythmia prevention	Coronary arteries	Cardiac tissue pathology
14.	Liver tumor necrosis	Inferior vena cava	Tumor
15.	None-malignant prostate treatment	Urethra	Sick prostate tissue
16.	Malignant prostate treatment	Urethra	Sick prostate tissue
17.	Artery aneurysms stabilization	All relevant arteries	Aneurysm wall
18.	Aortic aneurysms stabilization	Aorta	Aneurysm wall
19.	Berry aneurysms sealing	Brain arteries	Aneurysm wall
20.	Erectile dysfunction treatment	Internal Iliac	Artery media and adventitia

Table 2 below summarizes embodiments of the technology and uses.

TABLE 2

Summary of Technology

1. Technology
   - 1.1. The ultrasonic transducer:
     - 1.1.1. Very small: 1.5 × 8 [mm]
     - 1.1.2. Very thin: 0.8 [mm]
     - 1.1.3. Very high ultrasonic intensity output: 100 [W/cm^2] continuous
     - 1.1.4. Relatively high work frequencies: 10-25 [MHz].
     - 1.1.5. Biocompatible coating: Perylene
   - 1.2. The catheter
     - 1.2.1. Ultrasonic transducer cooling: vessel blood/liquid flow + catheter breading as heat sink
     - 1.2.2. Very flexible treatment tip: 10 mm stiff length. (Pass through 8 Fr "hokey-stick" guide catheter)
     - 1.2.3. Precise and easy torque following
     - 1.2.4. Standard 0.014 OTW
     - 1.2.5. Relatively small diameter: 6 Fr
   - 1.3. Distancing fixture
     - 1.3.1. Distancing transducer face from artery wall to prevent contact damage, with minimal mechanical forces on artery wall
2. Technology functionality
   - 2.1. Non-focused ultrasonic beam-like ultrasonic emission
     - 2.1.1. Simple anatomic
     - 2.1.2. Big treatment volume cross-section, the size of the transducer face(differing from focused ultrasound with small treatment volume)
     - 2.1.3. Relatively even spread of ultrasonic energy in beam cross-section (No need to precise anatomic positioning like in focused ultrasound)
   - 2.2. Treatment maneuverability and directionality
     - 2.2.1. Simple maneuvering with nearly 1:1 torquability.
     - 2.2.2. Simple treatment beam directivity feedback and control from standard angiograph (0, 90, 180, 270)
     - 2.2.3. No need for high operator skills
     - 2.2.4. No problem to use contrast agent during treatment
   - 2.3. Ultrasonic imaging using the unique transducer - Continuous measurement of distance to artery wall
     - 2.3.1. Treatment tip real positioning measurement (not possible only from angiography)
     - 2.3.2. Feedback to prevent high power operation of the transducer while touching the artery wall.
3. Tissue treatment
   - 3.1. Very fast treatment:
     - 3.1.1. Treatment duration of 30-5 sec per treatment point.
     - 3.1.2. Possibly 4 treatment point per artery for renal denervation
   - 3.2. Remote and localized effect
     - 3.2.1. Thermal effect volume in the tissue far from the transducer face: media, adventitia, Vasa-Vasorum, peri-adventitia, adventitia nerves, peri-adventitia nerves, peri-adventitia capillaries.
     - 3.2.2. Targeting tissues in varying distances from transducer face according to treatment parameters (not possible in most focused ultrasonic catheter designs)
     - 3.2.3. Possibility to apply thermal effect in tissues located 5 mm from the lumen wall. Relevant for peripheral nerves blocking from peripheral arteries.
     - 3.2.4. Non targeted tissues on the beam path to the target tissue are not damaged.
     - 3.2.5. Importantly no damage to the endothelium, basal membrane and internal elastic lamina.
   - 3.3. Tissue selectivity
     - 3.3.1. Highly selective remote thermal effect in nerve bundles that are covered with thick fat tissue. (most relevant to Renal Denervation in the Renal artery ostium)
   - 3.4. Treatment special features for Renal Denervation
     - 3.4.1. Working very close to artery ostium: <10 [mm]
     - 3.4.2. Working in short arteries: <20 [mm]
     - 3.4.3. Working in small arteries: 4-3 [mm]
4. Safety
   - 4.1. The temperature of the blood that flows over the ultrasonic transducer does not go over 50 C. while working in the maximal allowed operation intensity level 50 [W/cm^2].
   - 4.2. The temperature of the blood that flows over the ultrasonic transducer does not go over 43 C. while working in the therapeutic operation intensity level 30 [W/cm^2]. No need

TABLE 2-continued

Summary of Technology
to add external cooling saline injection.
4.3. The therapeutic treatment on the blood vessel wall is done with no mechanical contact with the vessel wall. No danger of damaging the vessel wall or disrupting any pathologies on the wall (Atherosclerosis plaques)
4.4. Localized and controlled effect specifically in the targeted treatment volume. No non-controlled energy effects in other tissues (unlike in RF treatment).
4.5. No blocking of the blood flow during the treatment
5. Possible implications
5.1. Much less pain in treatment: fast blocking of nerves with no electric excitation of the target nerve and no effect on other nerves (In contrast with Unipolar RF treatment)

Reference is now made to FIGS. **11-16** which illustrate experimental results following use of the device.

FIG. **11** is a histology slide, using H&E stain, and showing the thermal effect in a pig carotid artery. The border of the thermal effect region in the tissue is marked with a dashed line and noted as "Thermal Damage". The setup used was an ultrasonic catheter from inside the blood vessel.

FIG. **12** is a histology slide, using H&E stain, and showing the thermal effect in a pig renal artery. The border of the thermal effect region in the tissue is marked with a dashed line and noted as "Thermal". A necrotic nerve inside the thermal effect region is marked with an arrow and "necrotic nerve" text. The setup involved an ultrasonic catheter from inside the blood vessel.

It is noted that the embodiments cause thermal damage in target tissues far from the lumen internal wall, while causing no thermal damage in the lumen wall internal layer.

Specifically in blood vessels it was shown that thermal damage was achieved in the adventitia or media layers, without causing any apparent damage in the intima layer, either the endothelium or the elastic lamina.

It is believed that the reason for this effect is that the ultrasonic energy heats the artery wall all along the beam, but the blood flow in the lumen cools the tissue that is close to the blood flow, thus the endothelium wall never heats sufficiently to be damaged. It is possible to find a setting for the treatment parameters so to cause heating above 55 C of the tissues far from the blood flow, while the temperature of the intima layer is kept below 55 C.

Exemplary results are shown in FIGS. **13** and **14** which are histology slides wherein analysis and marking of the thermal damage area to a pig Carotid Artery and a Pig Renal Artery respectively, is made by a trained pathologist.

Heating the adventitia or media can cause blocking of the flow inside the small capillaries (called Vasa-Vasorum) in the blood vessel media and adventitia, for example by mechanical crimping due to the shrinking of the connective tissue due to collagen denaturation, or due to thrombotic blocking by a thrombus that is formed in the Vasa-Vasorum because of the thermal damage (the blood flow in these vessels is very low so it can not cool the blood vessel).

FIG. **15** illustrates exemplary results for the above. A histology slide shows analysis and marking of the blocked Vasa-Vasorum with arrows placed by a trained pathologist in a pig Carotid Artery Vasa-Vasorum in the adventitia.

The treatment is intended to provide extensive thermal damage to specific target tissues while keeping nearby tissues undamaged.

It is believed that the ultrasonic energy absorption is different for different kinds of tissue and, and furthermore, the content of collagen fibers may differ.

Specifically it was shown that in nerve fibers that are wrapped by fat tissue, it is possible to cause extensive thermal damage to the nerve tissue, while there is no significant thermal damage in the fat tissue or/and to the tissue surrounding them.

FIG. **16** illustrates two histology slides with analysis and marking of the thermal damage, or nerve degeneration area made by a trained pathologist, for a pig renal artery, and nerves in adventitia.

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

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

What is claimed is:

1. An ultrasonic transducer device comprising:

a first piezoelectric transducer;

a power unit enabling an ultrasonic power beam for tissue ablation in a tissue ablation region;

wherein said first piezoelectric transducer is mounted onto a base via only a preselected number of conductive mounting points;

wherein electrical communication between said transducer and said bas is carried out via said conductive mounting points;

wherein said mounting points are spaced apart from each other for providing at least a portion of a surface of said piezoelectric transducer with a relatively low level of damping;

wherein said damping is low enough to allow vibrations to mount up so as to be suitable for increasing power transmission efficiency; and

wherein said mounting points are heat conductive for transferring heat generated in said transducer.

2. The device of claim **1**, wherein said mounting is configured such as to provide a first region of said piezoelectric surface with, a first relatively high level of damping and a second region of said piezoelectric surface with a second relatively low level of damping, thereby to enable an ultrasonic sensing beam from said first region and said power transmission beam from said second region.

3. The device of claim **2**, wherein said first region comprises a first surface part of said piezoelectric surface and said second region comprises a second surface part of said piezoelectric surface, and a non-focused beam is provided from throughout said second surface part.

4. The device of claim **1**, comprising at least a second piezoelectric transducer sized for placement in a body lumen, the first piezoelectric transducer being provided with a first, relatively high level of damping and the second piezoelectric

transducer being provided with a second, relatively low, level of damping, and enabling an ultrasonic sensing beam from said first piezoelectric transducer and said ultrasonic power beam from said second piezoelectric transducer.

5. The device of claim **1**, wherein said first piezoelectric transducer is configured to provide said power transmission as a non-focused beam.

6. The device of claim **1**, configured to provide said power transmission in bursts having gaps and to transmit separate sensing transmissions during said gaps.

7. The device of claim **1**, wherein said mounting comprises an air pocket.

8. The device of claim **7**, wherein said mounting is provided with a surface tension sufficient to maintain said air pocket when said device is immersed in liquid.

9. The device of claim **1**, further comprising a matching layer for acoustic impedance matching placed on said piezoelectric surface wherein said matching layer comprises pyrolytic graphite.

10. The device of claim **1**, having a resonance and an anti-resonance, the device being used at a working frequency equal to said anti-resonance.

11. The device of claim **1**, wherein said power unit is further configured for enabling the ultrasound power beam for providing at least one of a mechanical effect, a pressure effect, a sub-pressure effect, and a cavitation effect.

12. The device of claim **11**, further comprising a cooling element configured to provide a cooling effect to the body lumen.

13. The device of claim **1**, wherein said preselected number is four.

14. The device of claim **1**, wherein said conductive mounting points comprise conductive glue.

15. The device of claim **1**, wherein a summed surface area of said conductive mounting points is small relative to said surface of said piezoelectric transducer.

16. The device of claim **1**, wherein said device further comprises a sensing unit enabling an ultrasonic sensing beam; wherein said power transmission enabled by said power unit is configured to provide a thermal effect to surrounding tissues, and said sensing unit is configured to provide imaging of said thermal effect.

17. The device of claim **16**, wherein said ultrasonic power beam and said ultrasonic sensing beam are enabled through said first piezoelectric transducer.

18. The device of claim **16**, wherein said sensing is usable in a control system to control treatment efficacy or device efficiency.

19. The device of claim **16**, wherein said thermal effect comprises denaturation of collagen and said sensing comprises detection of a change in reflected signal, or in backscatter.

20. The device of claim **16**, configured to be placed in a body lumen and wherein said sensing is configured to detect a lumen wall and to provide a signal to control for distance to the lumen wall and thereby ensure that the device does not touch said lumen wall.

21. The device of claim **1**, wherein said transducer is sized for placement in a body lumen.

22. The device of claim **21**, wherein said cooling element is configured for at least one of conduction and convection.

23. The device of claim **21**, wherein said body lumen is a blood vessel.

24. The device of claim **23**, configured with a catheter for placing within said blood vessel.

25. An ultrasonic transducer device comprising:

a first piezoelectric transducer configured for providing an ultrasonic power beam for tissue ablation;

wherein said first piezoelectric transducer is mounted onto a base via only a preselected number of conductive mounting points;

wherein electrical communication between said transducer and said base is carried out via said conductive mounting points;

wherein said mounting points are spaced apart from each other for providing at least a portion of a surface of said piezoelectric transducer with a relatively low level of damping;

wherein said damping is low enough to allow vibrations to mount up so as to be suitable for increasing power transmission efficiency; and

wherein said mounting points are heat conductive for transferring heat generated in said transducer.

* * * * *

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摘要(译)

一种用于组合传感和电力传输的双用超声换能器装置，包括第一压电换能器，其尺寸适于放置在体腔中;功率单元，其能够使超声功率束在组织消融区域中进行组织消融;以及感测单元，其使得超声感测束能够在所述组织消融区域处进行感测。在一个示例中，单个压电表面电连接到安装件;并且安装件为压电表面的第一区域提供第一相对高水平的阻尼，并且所述压电表面的第二区域具有第二相对低水平的阻尼，从而能够从所述第一区域进行感测并且从所述第二区域进行电力传输。区域。换能器效率或使用期间的处理的变化可以从脉冲响应或阻抗的变化或流过换能器的液体温度的变化推断。