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(54) **ULTRASONIC TRANSDUCERS**

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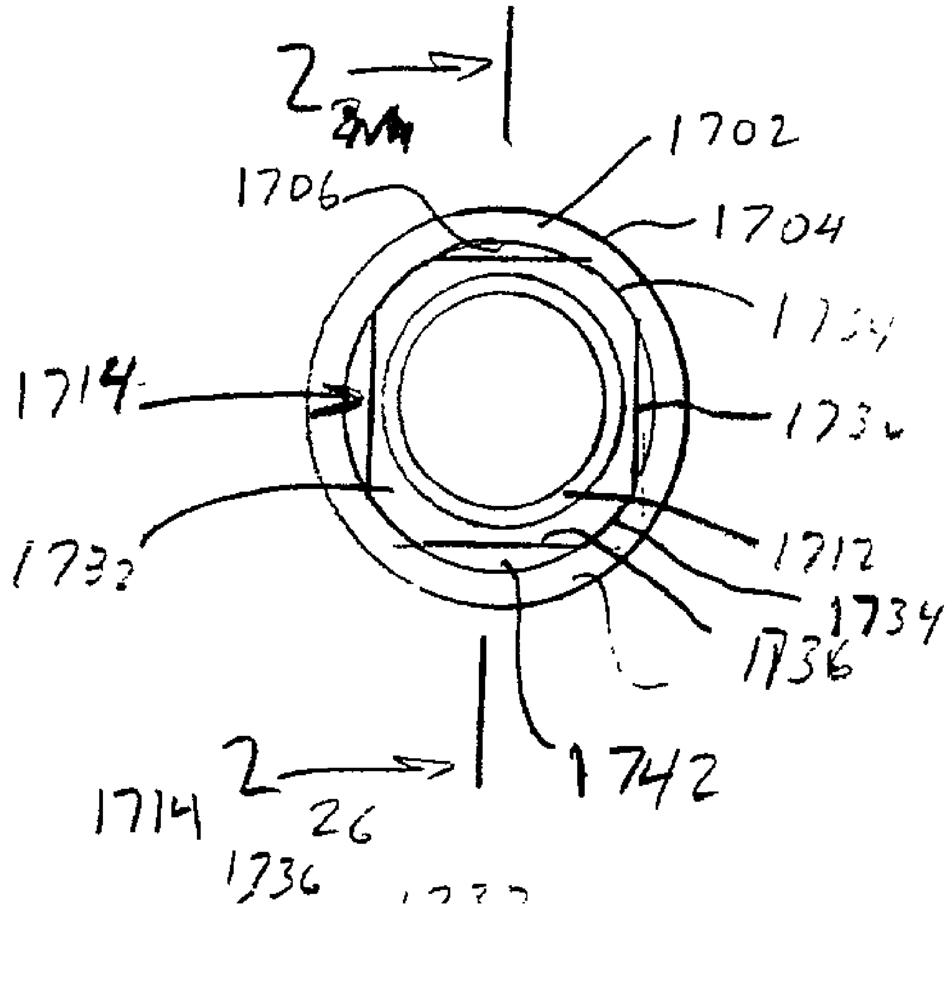
(57) **ABSTRACT**

A compact, high-power ultrasonic emitting transducer has an active element such as a piezoelectric element and structure defining a reflective backing interface such as an air interface behind the rear surface of the active element. A liquid is provided in the resonant unit between the backing interface and the active element.



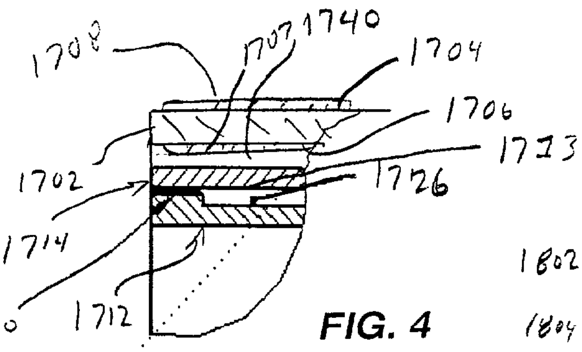


FIG. 4

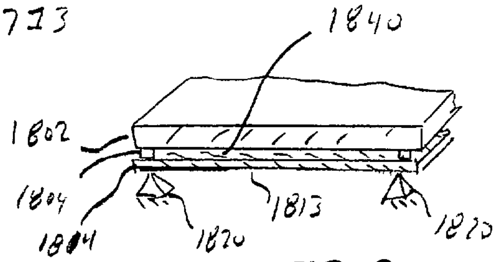


FIG. 6

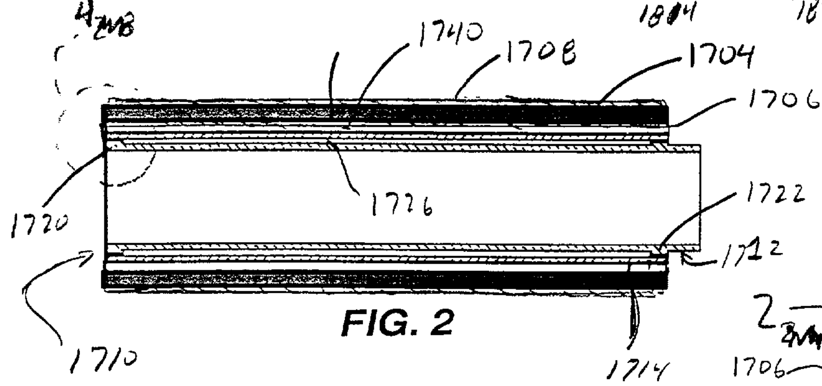


FIG. 2

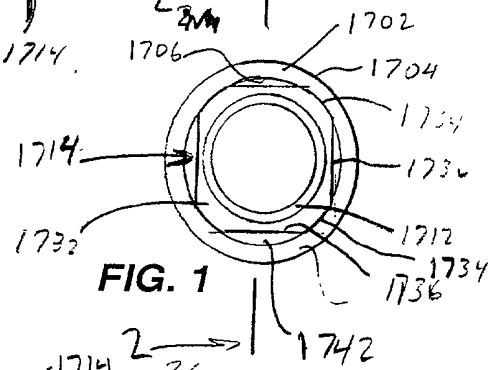


FIG. 1

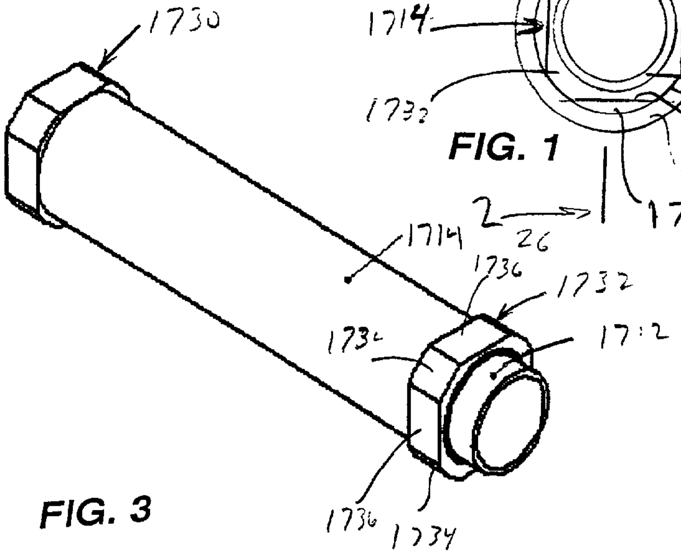


FIG. 3

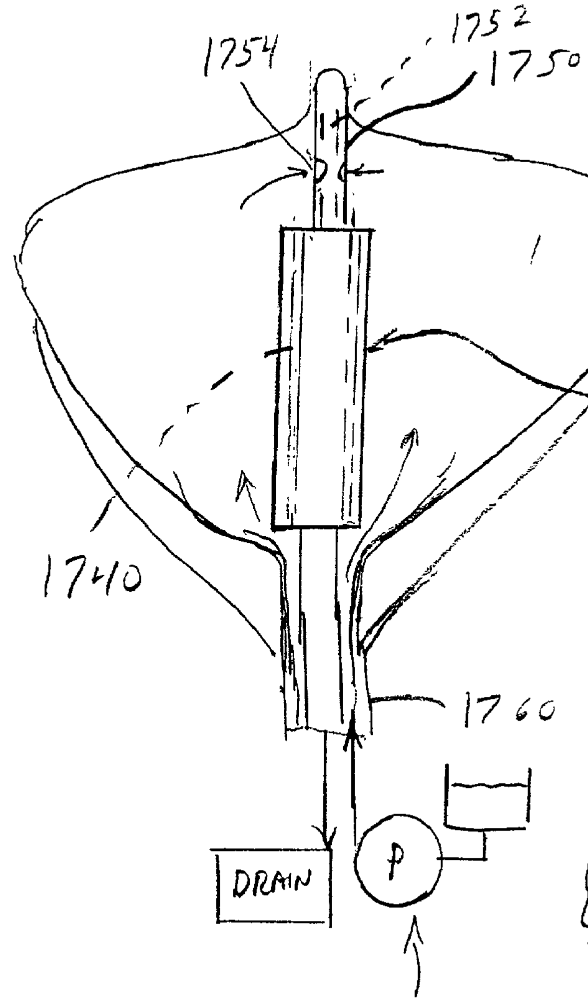

1752
1754
1750
1756
1758
1740
1760
DRAIN
P

FIG. 5

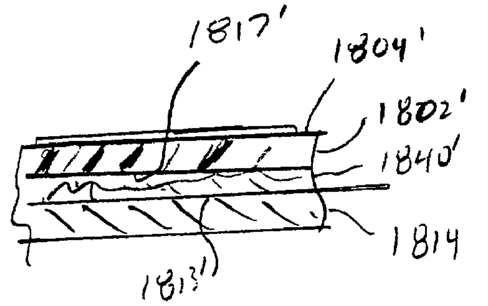

1817'
1804'
1802'
1840'
1814
1813'

FIG. 7

ULTRASONIC TRANSDUCERS

FIELD OF THE INVENTION

[0001] The present application relates to ultrasonic transducers.

BACKGROUND OF THE INVENTION

[0002] Ultrasonic transducers are used for a wide variety of applications including imaging, nondestructive testing and heating. For example, in certain medical procedures ultrasonic energy is applied to heat tissue within the body of a living subject. In an ablation procedure, the tissue is heated sufficiently to kill undesired tissue as, for example, to about 60-80 degrees C. In ablation and similar procedures, it is highly desirable to heat the undesired tissue rapidly, so as to minimize collateral damage to neighboring tissue. Certain ablation techniques use ultrasonic transducers which are inserted into the body as, for example, on a catheter. Such transducers must be compact, but should be capable of emitting substantial ultrasonic power.

[0003] A typical ultrasonic transducer includes an active element such as a piezoelectric or magnetostrictive element. The active element physically deforms in response to an applied drive signal, most commonly an electrical signal. In operation, the active element is driven by a signal at an ultrasonic driving frequency and produces ultrasonic vibrations. The transducer may consist only of the active element, but typically includes additional structural elements. The active element and these additional structural elements are arranged to form a composite structure which resonates at the driving frequency. The vibrations from this structure are emitted into the surrounding medium. For example, in a typical medical application, the ultrasonic vibrations are emitted from the transducer into a liquid or gel medium and are transmitted through this medium into the tissue.

[0004] Typically, the transducer is arranged to emit acoustic vibrations from a front surface into the surrounding medium. The transducer typically has one or more acoustically reflective interfaces remote from the front surface, and typically to the rear of the active element. The interface or interfaces help to direct the ultrasonic energy out of the transducer through the front surface. As further discussed below, the term "backing interface" is used to refer to an interface which plays a significant part in the operation of the transducer. The resonant unit includes the structure between the backing interface furthest from the front or emitting surface and the emitting surface.

[0005] Some transducers employ a solid backing element having acoustic impedance different from the acoustic impedance of the active element. For example, a transducer incorporating a polymeric piezoelectric active element may include a solid backing element formed from a metal or ceramic. The interface between the backing element and the polymeric active element serves as a backing interface.

[0006] Other transducers, referred to as "air-backed" transducers, have a structure which provides an air layer at the rear surface of the active element. For example, as shown in U.S. Pat. No. 5,620,479, the interior bore of a tubular ceramic element is filled with air. The interface between the air and the element is highly reflective, because air has an acoustic impedance far lower than that of the ceramic. This interface serves as a backing interface, and helps to direct acoustic vibrations through the outer surface of the tubular element, which serves as the front or emitting surface of the transducer.

[0007] Air-backed transducers can provide good efficiency and can be compact. However, the emitting power of such a transducer is limited by thermal considerations. Air and other gasses provide only a limited cooling effect at the rear surface of the active element. The power of the applied drive signal must be limited to avoid overheating the transducer. This problem is particularly severe in the case of small transducers for applications such as ablation.

[0008] Thus, despite the considerable effort applied heretofore in development of ultrasonic transducers, further improvement is needed.

SUMMARY OF THE INVENTION

[0009] The present invention addresses these needs.

[0010] One aspect of the present invention provides an ultrasonic transducer. The transducer in accordance with this aspect of the invention includes a resonant unit which in turn includes an active element having a front surface facing in a forward direction and having a rear surface facing in a rearward direction. The active element may be a piezoelectric element or other element operative to generate ultrasonic vibrations in response to an applied signal. The resonant unit includes a liquid disposed to the rear of said active element. For example, the liquid may be in contact with the rear surface of the active element. The resonant unit is resonant at an ultrasonic frequency and adapted to emit ultrasonic vibrations principally in said forward direction.

[0011] A further aspect of the invention provides an ultrasonic transducer including an active element having front and rear surfaces. Here again, the active element is operative to generate ultrasonic vibrations in response to an applied signal. The transducer further includes a rear structure defining a space disposed to the rear of said active element. A liquid is disposed in this space. The element, rear structure and liquid cooperatively form a resonant unit having a backing interface. The liquid is disposed between the backing interface and the rear surface of the active element. In a particularly preferred arrangement, the rear structure may include a wall having a front surface facing toward the space and a rear surface facing away from the space. A medium such as a gas having acoustic impedance lower than the acoustic impedance of the liquid abuts the rear surface of the wall to form a backing interface.

[0012] A transducer according to a further aspect of the invention includes an active element, rear structure and liquid as discussed above. In this aspect of the invention, the liquid partially defines a backing interface of the transducer. For example, the rear structure may include a solid wall to the rear of the space, the wall having acoustic impedance differing from the acoustic impedance of the liquid, so that the interface between the liquid and the wall serves as a backing interface.

[0013] Preferred transducers in accordance with these aspects of the present invention are compact and efficient. However, because the liquid is disposed within the resonant unit it can provide efficient cooling for the active element. The transducer desirably includes or is connected to a source of liquid arranged to move the liquid through the space. The most preferred transducers according to these aspects of the invention can provide output power higher than the power provided by an air-backed transducer of comparable size. Merely by way of example, a cylindrical, tubular transducer in accordance with one preferred embodiment is less 3 mm in diameter but can provide over 50 Watts of continuous acoustic output power at about 9 MHz when operated in water. The preferred transducers according to the foregoing aspects of the invention can be used in various applications. For example, such transducers are especially valuable in ultrasonic ablation devices for insertion into the body of a subject.

[0014] Other objects, features and advantages of the present invention will be more readily apparent from the detailed description of the preferred embodiments set forth below, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] **FIG. 1** is an end view of a transducer according to one embodiment of the invention.

[0016] **FIG. 2** is a sectional view of the transducer of **FIG. 1**.

[0017] **FIG. 3** is a perspective view of a part of the transducer of **FIGS. 1 and 2**.

[0018] **FIG. 4** is a fragmentary view on an enlarged scale of the area indicated in **FIG. 2**.

[0019] **FIG. 5** is a fragmentary sectional view of apparatus incorporating the transducer of FIGS. **1-4**.

[0020] **FIG. 6** is a fragmentary, diagrammatic perspective view of a transducer according to a further embodiment of the invention.

[0021] **FIG. 7** is a fragmentary sectional view of a transducer according to a further embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] An ultrasonic transducer or emitter in accordance with a preferred embodiment of the invention is depicted in FIGS. **1-4**. The emitter includes an active piezoelectric element **1702** in the form of a thin cylindrical tube having an exterior or front surface **1704** and an interior or rear surface **1706**. An electrode **1708** forms the front surface **1704** of the piezoelectric element, and a similar electrode **1707** forms the rear surface. The thickness of the electrode is greatly exaggerated in **FIGS. 2 and 4** for clarity of illustration. In practice, the electrode preferably is formed by a thin metallic coating, such as a plated or sputtered coating of metal on the order of a few thousand Angstroms thick overlying the actual piezoelectric material. An internal structure **1710** includes an inner support tube **1712** and an outer support tube **1714**. Support tubes **1712** and **1714** desirably are formed from a metallic, electrically conductive material. As best seen in **FIG. 4**, inner support tube **1712** has an outwardly projecting shoulder **1720** at one end. A similar shoulder **1722** is provided at the opposite end. Outer support tube **1714** has a cylindrical internal bore. Shoulders or rings **1720** and **1722** fit closely within the cylindrical bore of the outer support tube. Thus, over the major portion of the length of the support structure, between shoulders **1720** and **1722**, there is a gap **1726** between the inner surface of outer support tube **1714** and the outer surface of inner support tube **1712**. The tubes are sealed to one another at shoulders **1720** and **1722**. Gap **1726** is filled with a gas, such as normal room air, at the time the tubes are sealed to one another. This gas remains permanently within gap **1726**.

[0023] Outer support tube **1714** has a pair of outwardly projecting shoulders **1730** and **1732** at the ends of the outer support tube. Each shoulder has arcuate surfaces **1734** connected by flats **1736**, so that each shoulder is generally in the form of a square with rounded corners. The arcuate surfaces **1734** are concentric with the main portion of the support tube **1714**. Seen in end view, the flats **1736** are tangent to the cylindrical surface of the main portion of the support tube. As best seen in **FIG. 1**, the tubular piezoelectric electric element **1702** is supported on the arcuate surfaces **1734** of shoulders **1732** and **1730**, so that the inner surface **1706** of the piezoelectric element is concentric with the outer surface of support tube **1714**, but is spaced apart from the support tube so as to define a space in the form of a tubular passageway **1740** between the outer support tube and the inner or rear surface **1706** of the piezoelectric element. Passageway **1740** is open to the exterior of the transducer through small gaps **1742** defined between the inner surface **1706** of the piezoelectric element and the flats **1736** of the shoulders on the outer support tube.

[0024] In operation, the space or passageway **1740** is filled with a liquid. The front surface of the emitter (the front surface **1704** of the active piezoelectric element) is acoustically coupled to the medium which is to receive ultrasonic energy from the emitter.

[0025] For example, the emitter of FIGS. **1-4** may be used as the ultrasonic emitter in the apparatus described in copending, commonly assigned United States Patent Application of Todd Fjield et al. entitled Thermal Treatment Methods And Apparatus With Focused Energy Application filed of even date herewith, the disclosure of which is hereby incorporated by reference herein. Also, the emitter of FIGS. **1-4** may be used in the copending, commonly assigned United States Patent Application of Paul Harhen et al. entitled Energy Application With Inflatable Annular Lens, also filed of even date herewith, the disclosure of which is hereby incorporated by reference herein.

[0026] One apparatus incorporating the emitter of FIGS. **1-4** is shown in **FIG. 5**. This apparatus includes a probe structure incorporating a carrier catheter **1760**, a structural balloon **1756** having a proximal end connected to the carrier catheter, and a guide catheter **1750** extending through the lumen of the carrier catheter into or through structural balloon **1756**. Guide catheter **1750** has an internal lumen **1752** and one or more ports **1754** communicating with the interior space of the structural balloon **1756** adjacent the distal end of this balloon and distal to the transducer or emitter **1758**. The lumen of the carrier catheter is connected to a source **1761** of a liquid such as an aqueous liquid as, for example, water or saline solution, whereas the lumen of guide catheter **1750** is connected to a drain. The liquid source may include conventional fluid-handling elements as, for example, a reservoir containing a liquid and a pump or gravitational feed arrangement to convey the liquid through the system. The liquid is admitted from carrier catheter **1760** adjacent the proximal end of the balloon through an annular opening close to the proximal end of the transducer, so that the liquid flows generally in the distal direction. A significant portion of the flowing liquid will pass through the passageway or space **1740** within the transducer. The source and drain connections may be reversed to provide the opposite flow, with liquid admitted through ports **1754** and passing out through the proximal end of the balloon into carrier catheter **1760**. Also, the drain may be connected to feed the source, so that the liquid continually recirculates. Additionally, a baffle structure may be provided to direct more of the flowing liquid through passageway **1740**. At one extreme, the emitter may be sealingly connected to the carrier catheter **1760** or to the guide catheter **1752**, so that liquid can only enter the structural balloon through the passageway **1740** of the emitter, or so that liquid can only leave the structural balloon through passageway **1740**. In this manner, all of the fluid passing through the structural balloon is directed through the passageway **1740**. In the arrangement of **FIG. 29**, the front surface of the emitter is in contact with the liquid in the balloon **1756** so that the emitter can radiate ultrasonic energy into the liquid into the balloon; the liquid in the balloon serves as the medium coupled to the front surface of the emitter.

[**0027**] The air or other gas in gap **1726 (FIGS. 26, 28)** forms a highly-reflective interface **1713** with the metallic material of the outer support tube **1714**.

[**0028**] The reflectivity of an interface between two materials is determined mainly by the acoustic impedances of the materials on opposite sides of the interface. The reflectivity of the interface is given by the formula:

$$R=(Z_1-Z_2)/(Z_1+Z_2)$$

[**0029**] where:

[**0030**] R is the reflectivity of the interface;

[**0031**] Z_1 is the acoustic impedance of the material on one side of the interface; and

[**0032**] Z_2 is the acoustic impedance of the material on the other side of the interface.

[**0033**] Acoustic impedance is sometimes described as the acoustic velocity or speed of sound in a medium multiplied by the density of the medium. More accurately, acoustic impedance is defined as the acoustic pressure divided by the volume velocity. Volume velocity is the velocity that the particles in the medium are moving. Because wall **1714** is quite thin, the reflectivity of interface **1713** is determined in part by the acoustic impedance of the liquid in space **1740**, and, to some degree, by the acoustic impedance of the material in wall **1714**. Typical aqueous fluids have acoustic impedance of about 1.5 MRayls, whereas typical gases have acoustic impedance of less than about 10^{-4} Mrayls. The acoustic impedance of solids such as the metal in wall **1714** is far higher than that of typical gases. The reflectivity at the interface **1713** typically is at least about 0.9 and more typically nearly 1.0.

[**0034**] In operation, the emitter is excited by an electrical potential applied between electrodes **1707** and **1708**. This potential is applied at a predetermined ultrasonic drive frequency as, for example, about 1-15 MHz. The potential may be applied through electrical conductors (not shown) extending between the proximal end of the probe structure and the emitter, using a conventional ultrasonic-frequency driver (not shown). The reflective interface at surface **1713 (FIGS. 2 and 4)** and the outer surface **1704** of the emitter, and the stack of materials between these surfaces, constitute a resonant unit. As the piezoelectric material is excited, it repeatedly grows and shrinks in the forward-to-rearward direction of the stack, i.e., in the direction between surfaces **1704** and **1706**. The ultrasonic vibrations propagate through the stack, and are reflected forwardly at the interfaces within the stack and by the interface at surface **1713**, at the inner or rear surface of the stack. The dimensions of the various layers in the interior of the stack, between surfaces **1713** and **1704** (including the liquid layer within space **1740**) are selected so that the unit is resonant at the drive frequency, and so that the acoustic vibrations are emitted from the resonant unit principally through the front surface **1704** into the medium coupled to the front surface. That is, more energy passes through the interface **1704** at the outer or front surface of the stack than through interface **1713**. Although there is some reflectivity at interfaces within the stack, as at the interfaces bounding the liquid passageway **1740**, the reflective interface **1713** is effectively exposed to the ultrasonic vibrations in the stack and, thus, plays a substantial role in directing emissions to the front of the stack. The liquid within passageway **1740** effectively cools the piezoelectric element and other elements of the stack. Thus, the transducer element **1702** is cooled at both its front surface and its rear surface. This is in marked contrast to a conventional air-backed transducer. Such a transducer typically has a layer of air directly behind the rear surface of the piezoelectric element and, accordingly, has little or no heat transfer from the rear surface of the piezoelectric element. Surprisingly, an emitter in accordance with this embodiment of the invention can convert electrical power to acoustic power radiated into the surrounding medium through the front surface with an efficiency equal to the efficiency of an air-backed emitter. The emitter according to this embodiment of the invention, however, provides this efficiency in conjunction with better heat transfer and, hence, can operate at substantially higher power levels than the equivalent air-backed transducer of the same size.

[**0035**] The materials and dimensions of the various layers in the resonant unit desirably are optimized to assure maximum efficiency at the desired operating frequency. Conventional modeling techniques may be employed for such optimization. One such technique is the well-known KLM Model described in Krimholtz et al., "New Equivalent Circuits for Elementary Piezoelectric Transducers," Electronics Letters, Vol. 6, No. 13, pp. 398-399, Jun. 25, 1970, the disclosure of which is hereby incorporated by reference herein. The various layers can be modeled as one-dimensional elements, with the only dimension corresponding to the dimension in the forward-to-rearward direction of the stack, i.e., the radial dimension in the embodiment of FIGS. **1-4**. More accurate modeling can be provided by finite element analysis, or by physical testing. In the emitter of FIGS. **1-4**, the liquid in space or passageway **1740** forms an integral part of the resonant unit.

[**0036**] As discussed above, a resonant unit includes a front or principal emitting surface and includes one or more reflective interfaces disposed to the rear of the emitting surface. A reflective interface which is plays a substantial role in directing the acoustic energy out of the emitting surface is referred to in this disclosure as a reflective interface which provides a backing for the resonant unit. Thus, if the reflectivity of a particular interface disposed rearwardly of the emitting surface substantially affects the efficiency of the emitter, as where an arbitrary increase or decrease in the reflectivity of 50% or more could increase or decrease the efficiency of the emitter at its resonant frequency by 15% or more, that interface should be taken as a backing interface. A resonant unit can include one or more backing interfaces. The resonant unit also includes the materials disposed between the backing interface furthest to the rear and the front or emitting surface. Materials disposed to the rear of the most rearward backing interface do not form part of the resonant unit as considered herein. For example, the inner support tube **1712** and materials disposed inside the inner support tube are not considered part of the resonant unit. The inner support tube is effectively isolated from the ultrasonic vibrations in the resonant unit by reflective interface **1713**, which constitutes the most rearward backing interface. The wall thickness of the inner support tube can be varied at will (as by reducing the inside diameter of the inner support tube) without substantially affecting the efficiency of the resonant unit.

[**0037**] In the special case of a resonant unit which has two oppositely-directed principal emitting surfaces, the unit can be analyzed by considering one of these emitting surfaces as the front surface.

[**0038**] The optimum dimensions will vary with the desired operating frequency and with the materials employed. However, one exemplary embodiment uses a tubular piezoelectric element made from a ceramic lead zirconate-titanate composition, known in the art by the designation "PZT-8." The tubular transducer has an internal diameter of 83 mils (0.083 inches; 2.1 mm) and a wall thickness of 10.5 mils (0.27 mm), so that the outer diameter of the piezoelectric element is 103 mils (2.6 mm). The outer diameter of outer support tube **1714** is 72 mils (1.8 mm); and the annular passageway **1740** has a radial thickness of 5.5 mils (0.14 mm). The outer support tube is formed from half-hard brass and has a wall thickness of 5 mils (0.13 mm). The dimension between shoulders **1720** and **1722** is 325 mils (8.25 mm), and the effective length of the transducer is 8 mm. This transducer provides peak efficiency at a driving frequency of 9 MHz. When operated at 9 MHz, the transducer provides over fifty percent (50%) efficiency at electrical power levels between 20 and 100 watts. When cooled by water flowing at a rate of a few ml per minute, the transducer has been operated for periods of several minutes or more at input power levels up to 100 watts to provide approximately 51 watts of radiated acoustic power. It is believed that the transducer can be operated at even higher power.

[**0039**] Similar stacks can be made in planar form or in any other arbitrary form. A planar emitter schematically depicted in **FIG. 6** has a slab-like piezoelectric element **1802** spaced by stand-offs **1804** from a slab-like plate **1814**. The plate is supported at spaced-apart locations by supports **1820**. The rear surface of the plate **1813** is exposed to the atmosphere or other gas, or to another material having acoustic impedance different from that of plate **1814**. A layer of liquid **1840** is provided in the space or passageway between plate **1814** and piezoelectric element **1802**.

[**0040**] The reflective interface at the rear or inner surface of the stack need not be an air interface. For example, as shown in **FIG. 7**, the emitter or transducer may include a polymeric piezoelectric material such as a PVDF material **1802**', a liquid filled passageway **1840**' and a steel or other thick metallic element serving as the backing. In this instance, the interface **1813**' between the liquid and the metallic backing is substantially reflective. Interface **1813**' serves as a backing interface of the stack. Depending upon the reflectivity at this interface, it may be desirable to provide an additional backing interface to the rear of interface **1813**'. Here again, the liquid filled passageway is disposed between the piezoelectric element itself and a backing interface. In a further variant, an interface **1817**' at the front surface of the liquid layer may be highly reflective. For example liquid layer **1840**' may be formed from a liquid such as a liquid metal having acoustic impedance far higher than that of polymeric layer **1802**', or from a liquid having low acoustic impedance.

[**0041**] The transducers disclosed herein can be used as emitters in essentially any application where ultrasonic power is used. Also, active elements other than piezoelectric elements can be used. The active element can vibrate in any mode; it need not vibrate in the direction between the electrodes. Where a gas is used to form an interface, it is not essential to seal the gas within an enclosed space. However, where the gas is sealed in the transducer, as in the transducer of FIGS. **1**-**4**, the entire transducer can be exposed to liquids, as in the device of **FIG. 5**. There is no need to make a fluid-tight seal to the piezoelectric element. The liquid used in the space of the transducer may be the same as the medium present at the emitting surface, or may be different.

[**0042**] As these and other variations and combinations of the features discussed above can be employed, the foregoing description of the preferred embodiments should be taken by way of illustration rather than by way of limitation of the features discussed above.

1. An ultrasonic emitter comprising a resonant unit including an active element having a front surface facing in a forward direction and having a rear surface facing in a rearward direction, said active element being operative to generate ultrasonic vibrations in response to an applied signal, said resonant unit including a liquid disposed to the rear of said active element, said resonant unit being resonant at an ultrasonic frequency and adapted to emit ultrasonic vibrations at said ultrasonic frequency principally in said forward direction.

2. An ultrasonic emitter comprising:

(a) an active element having front and rear surfaces, said active element being operative to generate ultrasonic vibrations in response to an applied signal;

(b) a rear structure defining a space disposed to the rear of said active element,; and

(c) a liquid in said space,

said element, said rear structure and said liquid cooperatively forming a resonant unit, said resonant unit including a backing interface said element, said liquid being disposed between said backing interface and said rear surface of said active element.

3. An ultrasonic emitter comprising:

(a) an active element having front and rear surfaces, said active element being operative to generate ultrasonic vibrations in response to an applied signal;

(b) a rear structure defining a space disposed to the rear of said active element,; and

(c) a liquid in said space,

said active element, said rear structure and said liquid cooperatively forming a resonant unit, said resonant unit including a backing interface, said liquid at least partially defining said backing interface.

4. An emitter as claimed in claim 2 or claim 3, further comprising a source of liquid communicating with said space and an outlet communicating with said space, said source being operative to move said liquid through said space.

5. An emitter as claimed in claim 2 or claim 3, wherein said active element bounds said space whereby said liquid in said space is in contact with said active element.

6. An emitter as claimed in claim 3, wherein rear structure includes a solid wall disposed to the rear of said space, said wall having acoustic impedance differing from the acoustic impedance of said liquid, said wall and said liquid cooperatively defining said backing interface.

7. An emitter as claimed in claim 2 or claim 3, wherein said rear structure includes a wall having a front surface facing toward said space and a rear surface facing away from said space, and a medium having acoustic impedance lower than the acoustic impedance of said liquid, said medium abutting said rear surface of said wall.

8. An emitter as claimed in claim 7, wherein said medium is a gas.

9. An emitter as claimed in claim 2 or claim 3, wherein said active element is a piezoelectric element.

10. An emitter as claimed in claim 9, wherein said piezoelectric element includes electrodes at said front and rear surfaces.

11. An emitter as claimed in claim 2 or claim 3, wherein said active element is generally tubular, said front surface of said active element facing to the outside of the tubular element, said space and said reflective interface being disposed within the tubular element.

12. An ultrasonic emitter comprising:

(a) a tubular piezoelectric element having an interior bore, an inner surface bounding said bore and an outer surface;

(b) an interior structure extending within said bore, said interior structure including a first tube substantially coaxial with said tubular piezoelectric element so that said first tube and said piezoelectric element cooperatively define an annular passageway therebetween;

(c) a gas disposed within said first tube; and

(d) means for connecting the annular passageway to a source of a liquid.

13. An emitter as claimed in claim 12 further comprising a sealing structure at least partially sealing said first tube and confining said gas within said first tube.

14. An emitter as claimed in claim 12 further comprising a second tube substantially concentric with said first tube, said first and second tubes cooperatively defining an annular gap therebetween, said gas being disposed in said annular gap.

15. An emitter as claimed in claim 12, wherein said first tube is formed from a metal.

16. An emitter as claimed in claim 12, wherein said tubular piezoelectric element includes a ceramic piezoelectric material.

17. An emitter as claimed in claim 12, wherein said tubular piezoelectric element has cross-sectional dimensions of 4 mm or less.

18. A method of emitting ultrasound comprising the steps of:

(a) providing a resonant unit including an active element having a front surface facing in a forward direction and a liquid disposed to the rear of said active element, said resonant unit being resonant at an ultrasonic frequency; and

(b) driving said active element at said frequency so as to cause said active element to generate ultrasonic vibrations at said frequency, said resonant unit emitting ultrasonic vibrations principally in said forward direction.

19. A method as claimed in claim 18 further comprising the step of replacing said liquid during said driving step so that said liquid flows through said resonant unit and said liquid removes heat from said active element.

20. A method as claimed in claim 19, wherein said liquid is in contact with said active element.

21. A method as claimed in claim 18, wherein said resonant unit includes a reflective backing interface, said liquid being disposed between said reflective backing interface and said rear surface of said active element.

22. A method as claimed in claim 21, wherein said reflective backing interface includes a gas, said liquid being disposed between said gas and said rear surface of said active element.

23. A method as claimed in claim 18, wherein said resonant unit includes a reflective backing interface, and said liquid forms part of said reflective backing interface.

24. A method of emitting ultrasound comprising the steps of:

(a) driving an active element having front and rear surfaces at an ultrasonic frequency so that said active element generates ultrasonic vibrations at said frequency;

(b) passing a liquid through a space between the rear surface of the active element and an acoustically reflective interface so that said liquid removes heat from the active element and so that ultrasonic vibrations propagated from the rear surface of the active element pass through the liquid to the reflective interface, are reflected at the interface and pass back through the liquid to the active element, said reflective interface backing said element and directing the ultrasonic vibrations out of the element substantially through said front surface.

* * * * *

专利名称(译)	超声波换能器

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其他公开文献	US6763722
外部链接	Espacenet USPTO

摘要(译)

紧凑的高功率超声发射换能器具有诸如压电元件的有源元件和限定反射背衬界面的结构，例如在有源元件的后表面后面的空气界面。在背衬界面和有源元件之间的谐振单元中提供液体。