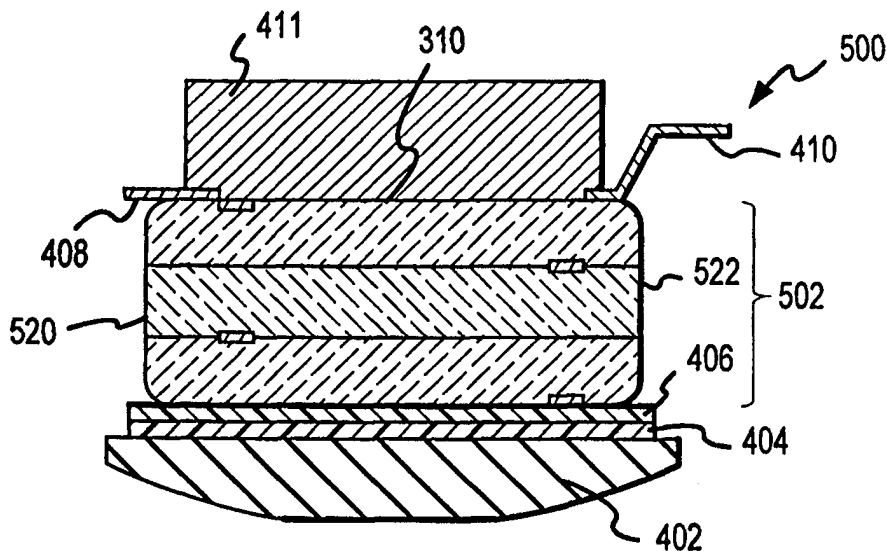




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(21) International Application Number: PCT/US00/02140 (22) International Filing Date: 28 January 2000 (28.01.00) (30) Priority Data: 60/117,869 28 January 1999 (28.01.99) US (71) Applicant (for all designated States except US): PARALLEL DESIGN, INC. [US/US]; 365 South 52nd Street, Tempe, AZ 85281 (US). (72) Inventors; and (75) Inventors/Applicants (for US only): CHANDRAN, Sanjay [IN/US]; 1258 West Myrna Lane, Tempe, AZ 85284 (US). CHARTRAND, David [US/US]; 1530 North Lewis Street, Mesa, AZ 85201 (US). (74) Agent: CARLSON, Brett, A.; Snell & Wilmer L.L.P., One Arizona Center, Phoenix, AZ 85004 (US).		(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>
(54) Title: MULTI-PIEZOELECTRIC LAYER ULTRASONIC TRANSDUCER FOR MEDICAL IMAGING (57) Abstract <p>A transducer (500) is tuned to a desired impedance by building piezoelectric assemblies of multiple layers (502), each layer acting as a parallel capacitor. Piezoelectric layers are preferably constructed by plating or otherwise placing a conducting perimeter (520, 522) around a piezoelectric substrate. Gaps are suitably formed in the conducting layer (520, 522) by dicing or otherwise to form distinct electrical conducting regions on each layer (520, 522). Piezoelectric layers are then suitably placed such that positive and negative conducting regions on each layer (520, 522) contact positive and negative regions on other layers. Layers are suitably joined by epoxy or by any other joining technique.</p>		



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Multi-Piezoelectric Layer Ultrasonic Transducer for Medical Imaging

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TECHNICAL FIELD OF THE INVENTION

This invention relates generally to ultrasonic transducers such as those used in medical imaging. More particularly, the invention relates to transducers with piezoelectric assemblies having multiple piezoelectric substrates.

10

BACKGROUND OF THE INVENTION

Transducers are devices that convert electrical energy to mechanical energy, or vice versa. Transducers in audio loudspeakers, for example, convert electrical signals into mechanical vibrations that in turn create audible sound waves. Similarly, transducers are often used to generate high frequency ultrasonic waves for various applications such as medical imaging, non-destructive evaluation (NDE), non-invasive surgery, dentistry and the like.

15

Transducers generally create ultrasonic vibrations through the use of piezoelectric materials such as certain forms of crystals (e.g. quartz) or ceramic polymers. Piezoelectric materials vibrate in response to alternating voltages of certain frequencies applied across the material. US Patent No. 5,637,800 issued June 10, 1997 to Finsterwald et al. and incorporated herein by reference, for example, discloses a transducer suitable for medical use that includes arrays of piezoelectric elements. Such a transducer is typically connected to electronics that drive the transducer via a coaxial cable or the like.

20

Piezoelectric elements are similar to common analog capacitors in that piezo elements generally include two electrodes separated by a piezoelectric material that functions as a dielectric. The overall capacitance of a transducer is dependent upon the area and the thickness of the piezo material. Because the piezo elements in many types of transducers (e.g. phased arrays, high density linear and curved arrays, high frequency linear arrays, multidimensional arrays and the like) are generally very small, such transducers generally exhibit relatively low capacitance. The low capacitance corresponds to a relatively high impedance compared to that of the drive electronics, which typically has an impedance on the order of 50-75 ohms. As is known in the art, the impedance mis-match between the transducer and the electronics results in inefficient transfer of electrical energy, undesirably high ringdown, excessive heat production (which can present a safety hazard if the transducer comes into contact with human skin), and the like. Hence, it is generally desired to match the impedance of the transducer to the impedance of the drive electronics. Impedance matching in this situation, however, can typically be quite difficult to accomplish in practice.

One method of decreasing the impedance of the transducer relative to the impedance of the electronics is to increase the capacitance of the transducer through the addition of external parallel capacitors or inductors. The addition of discrete elements, however, typically increases the cost, complexity and variability of the transducer. Other transducers have sought to reduce impedance by reducing the space between piezo elements (commonly called "kerf width") such that the total quantity of substrate used is increased. Reducing kerf width, however, places

piezo elements closer to each other, thus increasing undesirable cross-talk and resonance between piezo elements of the transducer. The overall performance of such transducers is therefore degraded.

Another strategy for reducing transducer impedance involves creating the
5 logical equivalent of parallel capacitors. One such method is disclosed by Richard L. Goldberg and Stephen W. Smith, "Multilayer Piezoelectric Ceramics for Two-Dimensional Array Transducers", IEEE TRANSACTIONS ON ULTRASONICS, FERROELECTRICS, AND FREQUENCY CONTROL, Vol. 41, No. 5, September 1994, pp. 761-771, incorporated herein by reference. This reference discloses a
10 piezoelectric element formed by placing green (i.e. unfired) ceramic between two electrodes with "fingers" that create additional capacitance. Such an element has several disadvantages in practice, however, in that it is generally difficult to manufacture and that the differentiation shrinkage (i.e. thermal contraction) between green ceramic and the electrode materials during the firing process
15 frequently results in cracks in the piezo element. Moreover, the conducting material in the electrodes frequently diffuses into the ceramic during the firing process, thus degrading the performance of the transducer. It is therefore desired to create an efficient and easily-manufacturable transducer having an impedance that can be matched to that of the drive electronics.

20

SUMMARY OF THE INVENTION

A transducer is tuned to a desired impedance by building piezoelectric assemblies of multiple layers, each layer acting as a parallel capacitor.

Piezoelectric layers are preferably constructed by plating or otherwise placing a conducting perimeter around a piezoelectric substrate. Gaps are suitably formed in the conducting layer by dicing or otherwise to form distinct electrical conducting regions on each layer. Piezoelectric layers may then be placed such that positive
5 and negative conducting regions on each layer contact positive and negative regions on other layers. Layers may be suitably joined by epoxy or by any other joining technique.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

10 Preferred exemplary embodiments of the present invention will hereinafter be described in conjunction with the appended drawing figures, wherein like numerals denote like elements and:

Figure 1 is a cross-sectional view of an exemplary substrate upon which an electrical conducting layer has been placed.

15 Figure 2 is a cross-sectional view of an exemplary piezoelectric element.

Figure 3 is a cross-sectional view of an exemplary piezoelectric assembly.

Figure 4 is a cross-sectional view of an exemplary transducer.

Figure 5 is a cross-sectional view of a second exemplary embodiment of a transducer.

20 Figure 6 is a cross-sectional view of a third exemplary embodiment of a transducer.

DESCRIPTION OF THE INVENTION

Although the preferred embodiment of the invention disclosed herein is primarily discussed in terms of a piezoelectric assembly for a medical imaging transducer, any number of other embodiments fall within the ambit of the present invention. For example, the devices and techniques described herein could be used in conjunction with other types of transducer systems, such as audio loudspeakers, non-destructive evaluation, non-invasive surgeries, dentistry and the like. Moreover, the spatial relationships described herein and in the drawing figures are merely for illustrative purposes, and indeed many spatial arrangements could be formulated within the ambit of the present invention.

The impedance of a transducer is dependent upon the impedance of the various piezoelectric assemblies. By increasing the overall capacitance of the piezo assemblies, the impedance of the transducer is reduced. One technique for increasing the capacitance of each piezoelectric assembly is to create "layers" of capacitive elements that act as parallel capacitors. It can be readily shown that for a piezoelectric assembly of fixed area and depth, the total capacitance of the assembly increases with the square of the number of piezo layers making up the assembly. For example, a three-layer assembly generally exhibits a capacitance that is nine times the capacitance of a similarly sized single layer assembly. By adjusting the number of layers used in a piezoelectric assembly, the capacitance of the assembly is therefore adjusted and the overall impedance of the transducer can be suitably tuned to a desired value.

With reference to Figures 1 and 2, a typical piezoelectric element (also referred to as a piezoelectric layer) suitably includes a substrate 104 and a conductive coating 102. Substrate 104 is made up of any suitable piezoelectric substrate material such as crystalline materials (e.g. quartz) or any of various forms of ceramic or polymer. A particularly suitable piezoelectric ceramic material is type 3203HD made by Motorola Ceramic Products of Albuquerque, New Mexico, which exhibits high density and strength characteristics that allow the cutting steps (described below) to be made without fracture of the individual elements.

Substrate 104 is preferably shaped to be generally rectangular, although substrates of other geometric configurations could be formulated. As shown in Figure 1, rectangular substrate 104 has a top 110, a bottom 112, a left side 106 and a right side 108. An exemplary substrate 104 has dimensions of approximately 13mm x 38 mm x 0.175 mm, although of course substrates of any size could be used in alternate embodiments.

Substrate 104 may be fired (i.e. sintered or densified) prior to the application of conductive coating 102. By using fired ceramic (as opposed to so-called "green" ceramic, which is unfired), diffusion of electrode material into the substrate is avoided, and electrical and acoustic properties are thereby preserved. Additionally, the cracking observed in "green" elements due to substrate differentiation shrinkage and thermal contraction during firing may be avoided.

Conductive coating 102 suitably covers at least a portion of substrate 104 to provide electrical excitation to the piezo material. Coating 102 is a metal or other electrical conductor. Suitable coatings may include chromium, gold, silver, nickel,

copper, aluminum, tin, various forms of solder, and the like. Alternatively, various conducting or non-conducting materials are suitably combined or formed in combination on substrate 104 to create conductive coating 102. In various embodiments, gaps 202 and 204 are made in coating 102 to form two electrically
5 isolated conductors (also referred to as electrodes) 206 and 208.

With reference to figure 1, individual ultrasonic piezo elements may be made in the following manner. A selected substrate material is made flat (e.g. by grinding) and suitably cut to a rectangular shape to form a substrate 104. Conducting layer 102 may be applied to substrate 104 by any method, such as
10 plating, spray coating, vacuum deposition or any other metalization technique. An exemplary method of applying conductive coat 102 involves first etching the surfaces of substrate 104 with an acid solution (such as a 5% fluoboric acid solution) and then plating substrate 104 with electroless nickel using conventional plating techniques. The plating material may be made to extend completely around
15 four adjoining surfaces of substrate 104 such that a perimeter of the substrate is suitably covered with conductive material and two faces (corresponding to the front and back faces parallel to the plane shown in Figures 1 and 2) of substrate 104 are left uncovered. Alternatively, substrate 104 is covered over all or nearly all of its surface area. In exemplary embodiments, a copper layer of approximately
20 two micron thickness is suitably electroplated or otherwise placed onto the first nickel layer (which is approximately 1 micron thick) followed by a thin layer of electroplated gold (which preferably has a thickness of slightly less than 0.1 microns) to protect against corrosion. Other conductive coatings 102 and methods

of applying the conductive coating could be formulated within the ambit of the present invention.

Two gaps 202 and 204 in coating 102 extend to the surface of piezoelectric substrate 104 to electrically isolate various regions of conductive layer 102 into
5 two electrodes 206 and 208. Any type of saw or other gap-forming mechanism is employed to form gaps 202 and 204. For example, gaps 202 and 204 can be created by placing a tape or layer of any other material on substrate 104 in the locations where gaps 202 and 204 are desired such that conductive material is easily removable after plating, or such that conductive material does not adhere to
10 substrate 104 in certain locations. In preferred embodiments, however, a wafer-dicing saw is used to create two cuts through conductive layer 102 to substrate 104.

Gaps 202 and 204 suitably form a rear surface electrode 208 and a separate front surface electrode 206. Each electrode 206 and 208 may include a wrap-around end that extends around a side of substrate 104 to the opposing side.
15 Stated another way, rear surface electrode 208 may extend around end 106 to a portion of front surface 110 of substrate 104. Similarly, front surface electrode 206 may extend around side 108 to overlap the rear face 112 of substrate 104. In various embodiments, the wrap-around ends extend approximately 1 mm along each side of the respective opposing surface, or as appropriate.

20 Electrodes 206 and 208 in piezo element 200 are thereby separated electrically by piezoelectric substrate 104, which preferably has a capacitance of approximately 400 pF at 1 kHz. When an electric potential having the proper frequency characteristics for the particular substrate material is applied across

electrodes 206 and 208, piezo substrate material 104 vibrates, thus generating sound waves of a comparable frequency. For example, an exemplary embodiment using 3203HD ceramic generates ultrasound waves at a center frequency of 3.5 MHZ. A capacitance that is proportional to the area of the two electrodes and
5 inversely proportional to the distance between the electrodes is also created. Piezo element 200 may therefore be logically represented as a capacitor in modeling diagrams.

With reference to Figure 3, an exemplary piezoelectric assembly 300 is suitably formed from two or more piezoelectric layers 200 such as those made in
10 accordance with the methods described above. As can be readily observed from Figure 3, front surface electrode 306 of element 304 suitably touches rear surface electrode 308 of element 302 to form a common electrical node (indicated by “-” signs in Figure 3). Similarly, the overlap portion of rear surface electrode 312 of element 304 suitably touches the overlap portion of front surface electrode 310 of
15 element 302, thus forming a second electrical node (indicated by the “+” signs in Figure 3). In various embodiments, a trench 324 isolating the first electrical node from the second electrical node is suitably formed by gaps 318 and 320.

The various piezo layers of piezo assembly 300 are suitably joined with an adhesive, by mechanical means, or by any other joining method. In an exemplary
20 embodiment, an epoxy adhesive bonds the layers. A suitable epoxy may be Epotek Model 330 available from Epotek Inc., although of course any suitable epoxy, bonding material or the like may be used in various embodiments. A coating of epoxy (such as a relatively thin coat of approximately 3 microns) may

be suitably applied between the piezo layers and allowed to settle, thus forming a bond between the layers. In preferred embodiments, trench 324 is also filled with epoxy.

Piezoelectric assembly 300 is then suitably incorporated into a transducer
5 element in any manner, such as according to the manner disclosed in US Patent No. 5,637,800 (previously incorporated by reference). Alternatively, piezoelectric assembly 300 can be suitably diced to create a multi-fingered piezo assembly. In such embodiments, a dicing saw or other cutting device is used to create cuts from the top or bottom of piezo assembly 300 through substrate 104. In an exemplary
10 embodiment, the cuts leave about 50 microns of material to the opposing face. Diced assemblies suitably allow the transducer to curve, thus facilitating ultrasonic focusing as described below.

Referring now to Figure 4, a piezo element suitable for use in a transducer 400 is shown. The multi-layer piezoelectric element 300 is preferably attached to
15 one or more acoustic matching layers 404 and 406. Acoustic matching layers 404 and 406 are each suitably formed of a polymer or polymer composite material, or of any other suitable damping material. In an exemplary embodiment, the epoxy material making up acoustic matching layer 406 is selected to be an epoxy having an intermediate acoustic impedance value between that of ceramic substrate 300
20 and the second acoustic matching layer 404. Material may be suitably cast and ground to a uniform thickness equal to approximately one-quarter wavelength of the desired operating frequency, as measured by the speed of sound in the particular material selected. The speed of sound in the human body is

approximately 1500 m/s, and an exemplary matching layer has a corresponding thickness of approximately 0.210 mm. An exemplary material for forming first matching layer 406 is Compound 1420 available from Bacon Industries, although other materials could be used in alternate embodiments.

5 The second acoustic matching layer 404 is similarly chosen to exhibit an intermediate acoustic impedance value between that of the first acoustic matching layer 406 and that of the material that the transducer is placed in contact with (e.g. the human body). In a particularly preferred embodiment, the second acoustic matching layer 404 is an epoxy similar to that used for the first acoustic matching
10 layer 406. In various embodiments the material may be suitably cast and ground to a uniform thickness equal to approximately one-quarter wavelength of the desired operating frequency as measured by the speed of sound in the particularly epoxy or other materials selected. A preferred embodiment uses a thickness of approximately 0.141 mm.

15 The acoustic matching layers 404 and 406 may be fastened to substrate 300 by a thin layer of epoxy 322, or by any other suitable joining mechanism. In various embodiments, the epoxy used to join substrate 300 to matching layers 404 and 406 is identical to the epoxy used in layer 322 to join the multiple layers of the substrate.

20 A backing material 411 may be placed on substrate 300 opposite the acoustic matching layers. Suitable backing materials include polymers such as polyurethane filled with, e.g., aluminum oxide or tungsten oxide. Backing material 411 may be cast or otherwise applied over the ceramic layer to encapsulate the

transducer elements and the corresponding signal and ground leads. The backing material may absorb and/or isolate the sound waves generated from the ceramic layer in order to preserve appropriate bandwidth for the particular transducer desired.

5 Similarly, a facing material 402 is preferably placed on the front face of the transducer next to acoustic matching layer 404. Any suitable facing material such as silicon rubber or polyurethane can be used. Various forms of facing materials may act as lenses to focus the acoustic waves to a particular focal point. Facing materials may additionally or alternatively serve as a protective seal. In various
10 alternative embodiments, the acoustic matching layers and /or piezo layers are suitably curved, angled or otherwise fashioned to focus the acoustic beam produced by the transducer. An example of a transducer having a curved piezo layer is disclosed in US Patent No. 5,637,800 (previously incorporated by reference), and the techniques of that reference may be easily combined with the
15 devices and methods disclosed herein.

 Signal leads 410 are also placed in contact with electrode 310 on substrate 300. Leads are attached to a control mechanism (not shown) to provide electrical energy to electrode 310. Similarly a ground lead 408 is attached to electrode 308 in order to provide electric potential between the two electrodes 310 and 308, thus
20 forming a capacitor. Although two positive leads 410 are shown in Figure 4, these leads are redundant and one lead may be omitted in alternate embodiments of the invention. Although terms such as “positive”, “negative” and “ground” are used herein to facilitate description, alternate embodiments reverse the polarity

described above. In particularly preferred embodiments, an AC potential is applied across leads 408 and 410. The leads are suitably connected to the two electrical nodes made up of the various electrodes of the piezoelectric layers such that electrical energy is preferably provided to each layer of the piezoelectric assembly.

5 With reference now to Figure 5, an alternate embodiment of a transducer 500 suitably includes multiple piezoelectric layers assembled to create a piezoelectric assembly 502 having two electrical nodes 520 and 522 as described above. Although three “levels” of piezo elements are shown in Figure 5, any number of levels could be used in alternate embodiments to “tune” the capacitance
10 of transducer 500 to any desired level. Leads 408 and 410 may be attached to electrical nodes 520 and 522, as appropriate. It will be appreciated that any number of piezo layers or assemblies could be combined to form transducer 500, as described more fully below.

Figure 6 is a cross-sectional view of an alternate embodiment of a
15 transducer 600. With reference to Figure 6, a transducer 600 may be prepared with a piezoelectric assembly 602 that includes a two or more piezoelectric layers 604, 606 and 608, as appropriate. Piezoelectric layers 604, 606 and 608 may be formulated as described above in conjunction with Figures 1-3, for example, or through any other suitable technique. As seen in Figure 6, however, each layer
20 604, 606 and 608 is coated with a conducting material only on the upper and lower faces of the substrate. Because the two faces are electrically isolated from each other by the substrate material itself, the embodiment may not require the notches described above for electrical isolation. The various layers may be arranged such

that the upper face of one layer (e.g. layer 604) is placed in contact with the bottom of another layer (e.g. layer 606) to create a common electrical node between the two layers. Leads 408 and 410 may be attached to each electrical node as appropriate.

- 5 Transducers as described above (e.g. in conjunction with Figures 4-6) exhibit a number of marked advantages over prior art transducers. Most notably, multi-layer substrate 300 allows the electrical impedance of the transducer to be reduced in accordance with the number of layers imposed. It has been observed in practice that the impedance of the transducer decreases inversely as the square of
- 10 the number of layers. As such, improved matching with electronic system transmit and receive characteristics is facilitated by “tuning” the piezo assembly with the desired number of joined piezo layers. The matched impedance allows more efficient operation of the transducer, because transducer gain is maximized between the transducer/electronics interface when impedance is properly matched.
- 15 A multi-layer transducer therefore exhibits a higher sensitivity than a comparable single layer transducer for a given transmit voltage. Similarly, a multi-layer transducer has a higher signal-to-noise ratio than a single layer transducer and a higher efficiency of electrical energy conversion to acoustic energy, thus allowing for less electrical energy to be input into the transducer to result in an equivalent
- 20 acoustic energy output. By reducing the amount of electrical energy required, less heat is generated in the transducer thus causing a reduction in the temperature of the transducer face. Since the transducer face is typically placed in contact with a patient, for example, the lower heat amount allows the transducer design to be in

accordance with stringent FDA standards relating to temperature. Hence, an improved transducer is created.

The corresponding structures, materials, acts and equivalents of all elements in the claims below are intended to include any structure, material or acts
5 for performing the functions in combination with other claimed elements as specifically claimed. The scope of the invention should be determined by the appended claims and their legal equivalents, rather than by the examples given above. Additionally, the various steps included in any method claims could be undertaken in any order or combined in any way while still falling under the ambit
10 of the present invention.

CLAIMS

1. A piezoelectric assembly for an ultrasonic transducer, the assembly comprising:

5 a first piezo layer comprising a first substrate having a first
conductive coating, said first coating having a first
electrode and a second electrode electrically isolated
from each other; and
a second piezo layer disposed adjacent to said first piezo
10 layer, the second piezo layer comprising a second
substrate having a second conductive coating, said
second coating having a third electrode and a fourth
electrode electrically isolated from each other; and
wherein said first and second piezo layers are affixed
15 together such that said first electrode and said third electrode
form a first electrical node and said second and fourth
electrodes form a second electrical node, said first and
second electrical nodes defining first and second capacitors
across said first and second substrates such that the total
20 impedance of said piezoelectric assembly is less than the
impedance of said first piezo layer.

2. The piezoelectric substrate of claim 1 wherein said first substrate and said second substrate comprise fired ceramic.

3. A method of fabricating a piezoelectric assembly in a transducer, the method including the steps of:

providing a first dielectric layer and a second dielectric layer;

coating at least a portion of each of said first and second dielectric layers with a

5 conducting material;

forming a first gap and a second gap in said conducting material coating said first

dielectric layer to define a first electrode and a second electrode;

forming a third gap and a fourth gap in said conducting material coating said

second dielectric layer to define a third electrode and a fourth electrode;

10 placing said first and second dielectric layers proximate to each other such that

said first and third electrodes are in electrical communication with each

other, and such that said second and fourth electrodes are in electrical

communication with each other; and

affixing said first dielectric layer to said second dielectric layer.

4. The method of claim 3 wherein said first and second substrates comprise fired ceramic.
5. The method of claim 4 wherein said coating step comprises the sub-steps of etching said portion of each of said first and second dielectric layers with an acid and plating said portion of each of said first and second dielectric layers with a metal.
6. The method of claim 3 wherein said portion of each of said first and second dielectric layers includes the perimeters of each of said first and second dielectric layers.
7. The method of claim 3 wherein said portion said first dielectric layer includes three sides of said first dielectric layer.
8. The method of claim 4 wherein said portion of each of said first and second dielectric layers includes the perimeters of each of said first and second dielectric layers.
9. The method of claim 4 wherein said portion said first dielectric layer includes three sides of said first dielectric layer.
10. A piezoelectric assembly fabricated by the method of claim 3.
11. A piezoelectric assembly fabricated by the method of claim 4.
12. A piezoelectric assembly fabricated by the method of claim 5.

13. A multilayered piezoelectric transducer assembly comprising:
a first piezoelectric layer having a first electrode, a second electrode and a first
dielectric material disposed therebetween;
a second piezoelectric layer having a third electrode, a fourth electrode and a
second dielectric material disposed therebetween;
an adhesive bonding said first and second piezoelectric layers such that said first
and third electrodes form a first electrical node and such that said second
and fourth electrodes form a second electrical node.

14. The piezoelectric transducer of claim 13 wherein said first and second dielectric
layers comprise fired ceramic.

15. The piezoelectric transducer of claim 13 wherein said transducer has a total
capacitance substantially equal to the sum of the capacitances of said first and second
piezoelectric layers.

16. The piezoelectric transducer of claim 13 further comprising:
a third piezoelectric layer having a fifth electrode and a sixth electrode forming
a third capacitor; and
a second adhesive bonding said third piezoelectric layer to said second
piezoelectric layer such that said first, third and fifth electrodes are in
electrical communication and such that said second, fourth and sixth
electrodes are in electrical communication with each other.

17. The piezoelectric transducer of claim 16 wherein said transducer has a total capacitance substantially equal to the sum of the capacitances of said first, second and third piezoelectric layers.

18. The piezoelectric transducer of claim 14 further comprising:

a third piezoelectric layer having a fifth electrode and a sixth electrode forming a third capacitor; and

a second adhesive bonding said third piezoelectric layer to said second

5

piezoelectric layer such that said first, third and fifth electrodes are in

electrical communication and such that said second, fourth and sixth

electrodes are in electrical communication with each other.

19. The piezoelectric transducer of claim 18 wherein said transducer has a total capacitance substantially equal to the sum of the capacitances of said first, second and third piezoelectric layers.

20. A method of formulating a transducer having a predetermined impedance, the method comprising the steps of:

formulating a piezoelectric assembly having a front face and a back face;

5

attaching said front face of said piezoelectric assembly to an acoustic matching layer; and

attaching a first electrical lead and a second electrical lead to said piezoelectric assembly;

wherein the step of formulating a substrate layer comprises the substeps of:

providing a plurality of piezoelectric layers, each of said plurality of piezoelectric layers having a substrate at least partially coated with an electrical conductor, each electrical conductor having a first cut and a second cut defining a first electrode and a second electrode;

5 aligning said piezoelectric layers such that said plurality of first electrodes are in electrical communication with each other and with said first electrical lead, and said plurality of second electrodes are in electrical communication with each other and with said second electrical lead to form a plurality of capacitive elements; and

10 joining said sublayers to each other with an adhesive.

21. The method of claim 20 wherein each of said piezoelectric portions comprise ceramic.

22. The method of claim 21 wherein each of said piezoelectric portions comprise fired ceramic.

23. The method of claim 20 wherein said providing step comprises applying an electrically conductive coating to at least a portion of the outer surfaces of each of said substrates.

24. A transducer formulated by the method of claim 20.

25. A transducer formulated by the method of claim 23.

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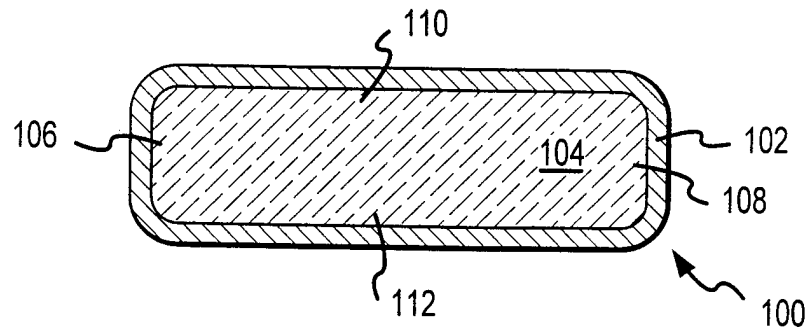


FIG. 1

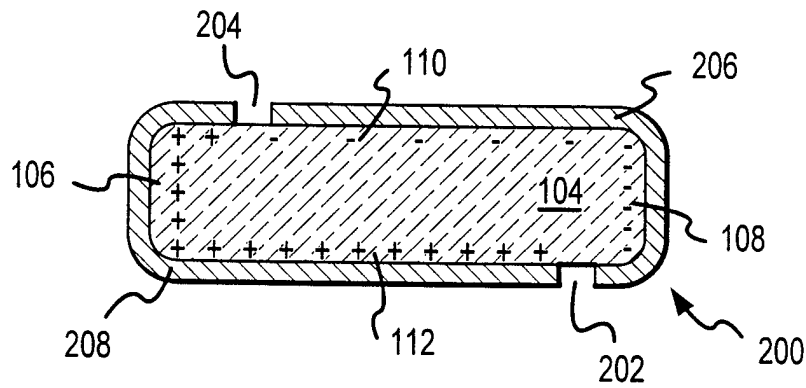


FIG. 2

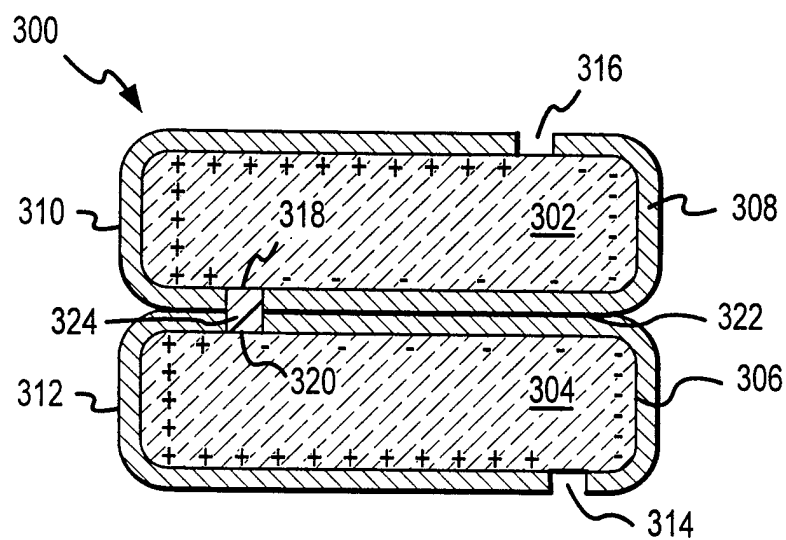


FIG. 3

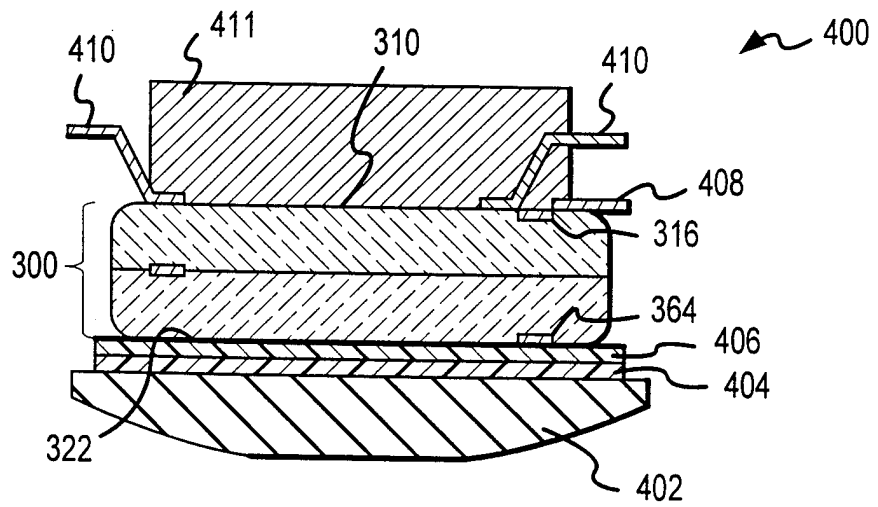


FIG. 4

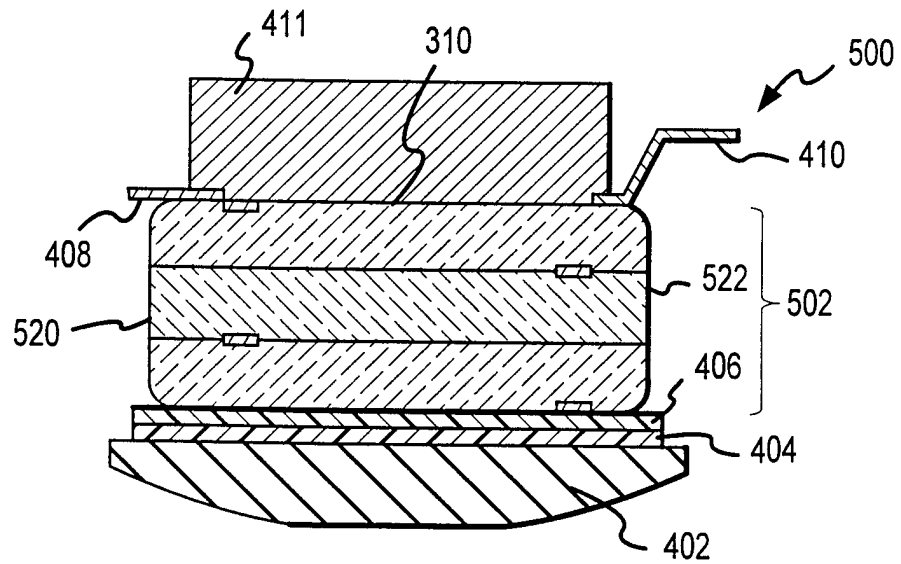


FIG. 5

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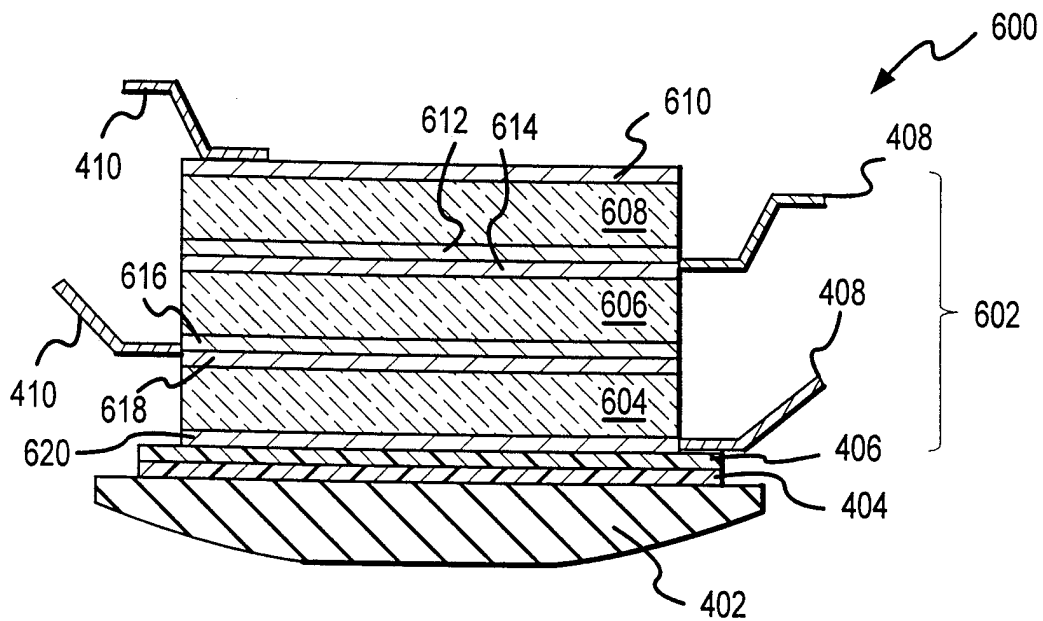


FIG.6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/02140

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : HO1L 41/04
US CL : 310/334, 322, 335, 336, 337, 365, 366
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 310/334, 322, 335, 336, 337, 365, 366

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,329,496 A (Smith) 12 July 1994 (12.07.1994), fig 1.	1, 2, and 13-25
A	US 5,637,800 A (Finsterwald et al) 10 June 1997 (10.06.1997), entire document.	1, 2, and 13-25
A	US 5,704,105 A (Venkataramani et al) 06 January 1998 (06.01.1998) entire document.	1, 2, and 13-25
X	US 5,744,898 A (Smith et al) 28 April 1998 (28.04.1998) fig. 1.	1, 2 and 13-25
A	US 5,834,880 A (Venkataramani et al) 10 November 1998 (10.11.1998) entire document.	1, 2, and 13-25

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier document published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

02 MAY 2000

Date of mailing of the international search report

13 JUL 2000

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专利名称(译)	用于医学成像的多压电层超声换能器		
公开(公告)号	EP1171919A1	公开(公告)日	2002-01-16
申请号	EP2000905785	申请日	2000-01-28
[标]申请(专利权)人(译)	并行设计		
申请(专利权)人(译)	并行设计，INC.		
当前申请(专利权)人(译)	并行设计，INC.		
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IPC分类号	G01N29/24 A61B8/00 B06B1/06 H01L41/047 H01L41/09 H02N2/04 H04R17/00 H01L41/04		
CPC分类号	B06B1/0611 H01L41/0471 H01L41/0475 H01L41/277 Y10T29/42 Y10T29/49005 Y10T29/49155 Y10T29/49156		
优先权	60/117869 1999-01-28 US		
其他公开文献	EP1171919A4		
外部链接	Espacenet		

摘要(译)

通过构建多层（502）的压电组件将换能器（500）调谐到所需的阻抗，每层用作并联电容器。压电层优选地通过电镀或以其他方式在压电基板周围放置导电周边（520,522）来构造。通过切割或以其他方式在导电层（520,522）中适当地形成间隙，以在每个层（520,522）上形成不同的导电区域。然后适当地放置压电层，使得每层（520,522）上的正和负导电区域接触其他层上的正区域和负区域。层适当地通过环氧树脂或通过任何其他连接技术连接。