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(54) MULTILAYER ULTRASONIC TRANSDUCER AND METHOD FOR MANUFACTURING SAME

MEHRSCHICHT-ULTRASCHALLWANDLER UND VERFAHREN ZU SEINER HERSTELLUNG

TRANSDUCTEUR ULTRASONIQUE A COUCHES MULTIPLES ET PROCEDE DE FABRICATION CORRESPONDANT

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(56) References cited:

EP-A2- 0 451 984	**EP-A2- 1 006 596**
AT-B- 271 947	**DE-A1- 3 330 538**
US-A- 6 121 718	**US-A1- 2003 107 303**

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Description

Technical Field

[0001] The present invention relates to a multilayer ultrasonic transducer and a method for the manufacture thereof; and, more particularly, to a multilayer ultrasonic transducer with an improved vibration feature and a method for the manufacture thereof.

Background Art

[0002] Ultrasonic transducers for medical imaging have many components, and pitches among the components are getting smaller. As the dimensions of the components in an ultrasonic transducer decrease, a mismatch of electrical impedance between an ultrasonic image diagnostic system the ultrasonic transducer and an ultrasonic image diagnostic system is rising as a serious problem yet to be solved.

[0003] In general, electrical impedance of the components in an ultrasonic transducer ranges from 100 ohms to 500 ohms while electrical impedance of typical cables used to communicate between the ultrasonic transducer and the ultrasonic image diagnostic system ranges from 50 ohms to 85 ohms, exhibiting great difference therebetween. Such a mismatch deteriorates an energy transduction efficiency, which in turn results in a deterioration of sensitivity of the transducer and an increase of a signal-to-noise ratio, thereby impeding a signal processing for the representation of an ultrasonic image. The most important factors in ultrasonic image diagnosis are brightness and resolution of the image. However, the mismatch of the electrical impedance between the ultrasonic transducer and the ultrasonic image diagnostic system hinders the representation of a bright image.

[0004] In case piezoelectric substrates of same thicknesses are connected to each other in series acoustically but in parallel elastically, a relationship between voltage, impedance and the number of the piezoelectric substrates can be expressed as follows (see, Michael Greenstein and Umesh Kumar, "Multilayer piezoelectrical resonators for medical ultrasound transducer", IEEE Transactions Ultrasonics, Ferroelectrics and Frequency Control, vol. 43, pp. 622-624, 1996):

$$V(N) = V(1)/N$$

$$Z(N) = Z(1)/N^2$$

where N, V, and Z represent the number of the wafers, voltage and impedance, respectively.

[0005] That is, as the number of the piezoelectric substrates increases, the impedance decreases in proportion to the square of N. Thus, by reducing the high impedance of the transducer's components based on this principle, it is likely that the above-mentioned mismatch problem would be solved.

[0006] In this regard, there have been made many attempts to apply a multilayer piezoelectric transducer to a medical ultrasonic transducer (see, David M. Mill et al., "Multi-layered PZT-Polymer Composites to increase signal to noise ratio and resolution for medial ultrasound transducer", IEEE transactions on ultrasonics, ferroelectrics, and frequency control, Vol. 46, No. 4, July 1999).

[0007] Such a multilayer piezoelectric ultrasonic transducer as mentioned above, however, has a drawback in that it has a poor vibration feature because an additional layer besides a matching layer is coupled to a front surface of the transducer. For example, US Patent Nos. 6,121,718 and 6,437,487 disclose multiplayer ultrasonic transducers using piezoelectric materials, wherein FPCBs (Flexible Printed Circuit Boards) are formed on both the front and the rear surface of a stacked assembly for electrical connection. Therefore, the stacked assembly has a configuration in which a FPCB formed of a polyimide/Cu layer of several tens of microns or a Cu layer of several tens of micrometers is deposited on the front surface of the multilayer transducer. As a consequence, the vibration feature of the stacked assembly becomes poor.

Disclosure of Invention

Technical Problem

[0008] It is, therefore, an object of the present invention to provide a multilayer piezoelectric substrate assembly for use in an ultrasonic transducer and the method of fabricating thereof.

[0009] Another object of the present invention is to provide a multilayer ultrasonic transducer with an improved vibration feature employing the multilayer piezoelectric substrate assembly and a method of fabricating thereof.

Technical Solution

[0010] In accordance with a first aspect of the present invention, there is provided a multilayer piezoelectric substrate assembly, comprising: a first piezoelectric substrate having a first electrode layer formed on a first and a second main surface and a first and a second side surface thereof, the first piezoelectric substrate having a first and a second discontinuity on the first and the second main surface to divide the first electrode layer into a first electrode and a second electrode isolated from each other; and a second piezoelectric substrate having a second electrode layer formed on a first and a second main surface and a first and a second side surface thereof, the second piezoelectric substrate having a third and a fourth discontinuity to divide the second electrode layer into a third and a fourth electrode isolated from each other, the third discontinuity being formed on the first main surface, wherein the first and the second piezoelectric substrates are coupled each other such that the second and the third discontinuities are faced each other, to thereby form a first electrode node and a second electrode node, the first electrode node having the first and the third electrodes and the second electrode node having the second and the fourth electrodes, and the multilayer piezoelectric substrate assembly being characterised in that the fourth discontinuity is formed between the second main surface and the second side surface of the second piezoelectric substrate by abrasion.

[0011] In accordance with a second aspect of the present invention, there is provided a multilayer ultrasonic transducer including the multilayer piezoelectric substrate assembly as described above.

[0012] In accordance with a third aspect of the present invention, there is provided a method for fabricating a multilayer piezoelectric substrate assembly comprising the steps of: preparing a first and a second piezoelectric substrate having electrode layers of conductive materials deposited on a first and second main surface and a first and second side surface thereof, respectively; forming a first and a second discontinuity and a third and a fourth discontinuity on the first and second main surface of the first and the second piezoelectric substrates to divide the electrode layers into a first and a second electrode and a third and a fourth electrode isolated from each other, respectively; and laminating the first and the second piezoelectric substrates on top of each other by allowing the second discontinuity of the first piezoelectric substrate to face the third discontinuity of the second piezoelectric substrate, to thereby form a first electrode node having the first and the third electrode being coupled to each other and a second electrode node having the second and the fourth electrode being coupled to each other, and the method for fabricating a multilayer piezoelectric substrate assembly being characterised in that the fourth discontinuity is formed between the second main surface and the second side surface of the second piezoelectric substrate by abrasion.

[0013] In accordance with a fourth aspect of the present invention, there is provided a method for fabricating a multilayer ultrasonic transducer including the multilayer piezoelectric substrate assembly fabricated by the steps as described above.

Advantageous Effects

[0014] As described, the technical feature of the present invention resides in that the separation of the electrodes can be achieved by forming the discontinuities and abrading the edge portion in fabricating the multilayer piezoelectric substrate assembly for use in manufacturing the multilayer ultrasonic transducer in accordance with the present invention. By using the multilayer substrate assembly with such a configuration, the ground flexible printed circuit board is coupled to the multilayer piezoelectric substrate assembly by using only the edge portion and the side surface of the electrode, which allows omitting an additional layer to be deposited between the front surface of the multilayer piezoelectric substrate assembly and the matching layer. As a result, it is possible to provide the multilayer ultrasonic transducer with an improved vibration feature, a wide bandwidth and a high sensitivity.

[0015] The method of fabricating the multilayer piezoelectric substrate assembly in accordance with the present invention can be used in case of using piezoelectric single crystals as well as using piezoelectric ceramics. Conventionally, an ultrasonic transducer using a piezoelectric single crystalline has a bandwidth 40 % to 50 % greater than that of a conventional one using a piezoelectric ceramic such as PZT and is capable of realizing a high resolution in an ultrasonic image diagnosis. However, the ultrasonic transducer using the piezoelectric single crystalline substrate also has the same problem as in the one using the piezoelectric ceramic substrate in that the mismatching between the components of the transducer and the system is great, so it is difficult to improve sensitivity and an S/N ratio of the transducer. Further, since the piezoelectric single crystalline substrate is very weak mechanically and thermally, it is readily destroyed during a machining process including grinding, lapping, dicing steps and a transducer manufacturing process involving a bonding step, etc. In accordance with the present invention, however, no layer exists on the front surface of the transducer, so the conventional problem of the reduction in sensitivity can be solved, and the probability of the piezoelectric single crystalline substrate being broken during the manufacturing process, for the separation of the electrodes is done in a simple way such as an edge abrasion.

[0016] Piezoelectric elements formed of piezoelectric single crystals in accordance with the present invention provides a higher permittivity compared to piezoelectric elements formed of PZT type ceramics that are common in the art. Therefore, by using the piezoelectric elements formed of piezoelectric single crystals in accordance with the present invention, a loss of a cable or an equipment caused by a stray capacitance thereof can be reduced, which makes it possible to obtain a high-sensitivity signal.

Brief Description of the Drawings

[0017] The above and other objects and features of the present invention will become apparent from the following description of preferred embodiments given in conjunction with the accompanying drawings, in which:

[0018] Figs. 1 to 7 illustrate a sequential process of fabricating a multilayer piezoelectric substrate assembly in accordance with the present invention;

[0019] Figs. 8 to 10 show a sequential process of fabricating a multilayer ultrasonic transducer using the multilayer piezoelectric substrate assembly shown in Figs. 1 to 7;

[0020] Fig. 11 presents a schematic diagram of the multilayer ultrasonic transducer shown in Fig. 10;

[0021] Figs. 12 and 13 describe a waveform and a frequency spectrum showing a vibration feature of a PZT single-layer transducer, respectively;

[0022] Figs. 14 and 15 illustrate a waveform and a frequency spectrum showing a vibration feature of a PMN-PT single-layer transducer, respectively; and

[0023] Figs. 16 and 17 demonstrate a waveform and a frequency spectrum showing a vibration feature of a multilayer ultrasonic transducer in accordance with the present invention.

Best Mode for Carrying Out the Invention

[0024] Hereinafter, preferred embodiments of the present invention will be described with reference to the accompanying drawings.

[0025] A multilayer ultrasonic transducer in accordance with the present invention is fabricated through a process sequentially illustrated in Figs. 1 to 10.

[0026] As shown in Fig. 1, first of all, two piezoelectric substrates, only one of them being shown in this drawing for simplicity, are prepared. Although there is shown and described that two piezoelectric substrates are used in this embodiment, it is also possible to use more than two piezoelectric substrates, to thereby fabricate a multilayer ultrasonic transducer with three or more substrate s layers if necessary. These piezoelectric substrates are employed to vibrate when applying alternating current (AC) thereto to generate ultrasonic signals in the ultrasonic transducer. A first piezoelectric substrate 10 has a first main (or a top) surface 12, a second main (or a bottom) surface 14, a first (or a left) side surface 16 and a second (or a right) side surface 18.

[0027] Then, as illustrated in Fig. 2, an electrode layer 21 of an electrical conductive material is evenly deposited on each of the four surfaces 12 to 18 of a first piezoelectric substrate 10 by employing a sputtering, an electronic beam, a thermal evaporation or an electro plating method. Subsequently, first and second discontinuities 32 and 34 are formed on the first and the second main surfaces 12 and 14 of the first piezoelectric substrate 10 such that they are elongated along a lengthwise direction of the first and the second side surfaces 16 and 18, respectively. By forming the first and the second discontinuities 32 and 34, the electrode layer 12 is divided into a first and a second electrode 22 and 24 isolated from each other, thus obtaining the first piezoelectric substrate 10 having the two isolated electrodes 22 and 24 formed thereon. The first and the second electrodes 22 and 24 will be served as a primary (minus) electrode and a secondary (plus) electrode, respectively.

[0028] The piezoelectric substrate 10 for use in the present invention may be a piezoelectric ceramic substrate or a single crystalline piezoelectric substrate, having a thickness ranging from about 22 □ to 500 □ and, preferably, ranging from 50 □ to 220 □.

[0029] The electrodes 22 and 24 may be formed of a conductive film made of chrome, copper, nickel, gold, or the like, and the thickness of the electrodes 22 and 24 may range from about 100 Å to 1000 Å (10Å = 1 nm).

[0030] Such an isolation of the electrode layer 21 can be achieved by forming the discontinuities of certain thickness by using, for example, a dicing saw. Specifically, the first and the second discontinuities 32 and 34 are formed at a predetermined distance from the opposite edges of first and second surfaces 12 and 14 of the first piezoelectric substrate 10, respectively, to thereby divide the electrode layer 12 into (a) the first electrode 22 covering a minority part of the second main surface 14, the first side surface 16 and a majority of the first main surface 12; and (b) the second electrode 24 covering a minority part of the first main surface 12, the second side surface 18 and a majority of the second main surface 14.

[0031] The first discontinuity 32 is formed at a position spaced from the right edge of the first main surface 12 of the first piezoelectric substrate 10, wherein the spaced area will be used to accommodate an adhesive for coupling the electrode layer 21 and a ground electrode plate (not shown). For instance, the first discontinuity 32 is preferably formed to have a width of about 0.03 mm to 0.1 mm and formed at a distance about 1 mm to 1.5 mm inward from the right edge of the first main surface 12. Meanwhile, the second discontinuity 34 is preferably formed to have a width of about 0.2 mm to 0.5 mm and formed at a distance 1 mm to 1.5 mm inward from the left edge of the second main surface 14.

[0032] According to the present invention, it is preferred that the second discontinuity 34 is formed to be wider than the first discontinuity 32. Further, it is preferable that the first and the second discontinuities 32 and 34 have the depths equivalent to about 70 % to 80 % of the thickness of the first piezoelectric substrate 10 in order to suppress the generation of vibrations. The adhesive used to couple the electrode layer 21 and the ground electrode plate may be an epoxy paste and, preferably, a silver epoxy paste.

[0033] Then, another piezoelectric substrate is prepared and fabricated as follows. As shown in Fig. 4, an electrode layer of an electrical conductive material is deposited on four surfaces of the other one of the two substrates, i.e., a second piezoelectric substrate 20, through the use of the same method as described in Fig. 2, and then a third discontinuity 36 is formed in the electrode layer 21 on a first main surface 12. Further, the electrode layer 21 at an edge portion between a second main surface 14 and a second side surface 18 is abraded along the lengthwise direction of the second side surface, thus forming a fourth discontinuity 38 in the form of an edge discontinuity 38. As similar as described above, therefore, the electrode layer is divided into a third and a fourth electrodes 26 and 28 isolated with each other, to thereby obtain the second piezoelectric substrate 20 having the isolated electrodes 26 and 28 formed thereon. The third and the fourth electrodes 26 and 28 will be served as a secondary (plus) and a primary (minus) electrodes, respectively.

[0034] More specifically, the third discontinuity 36 is formed on the first main surface of the second piezoelectric substrate 20 such that it is distanced away from the left edge of the first main surface 12 of the second piezoelectric substrate 20, wherein the distance away from the left edge is the same interval as that maintained between the first side surface of the first piezoelectric substrate 10 and the second discontinuity 34 in Fig. 2. Further, the third discontinuity 36 has the same shape as that of the second discontinuity 34, and the edge discontinuity 38 is formed by abrasion.

[0035] Subsequently, the first and the second piezoelectric substrates 10 and 20 having the electrodes formed thereon as described above are polarized as shown in Figs. 3 and 5, respectively, so that the first and the fourth electrodes 22 and 28 are polarized as primary (minus) electrodes, while the second and the third electrode 24 and 26 are polarized as secondary (plus) electrodes. Then, the first piezoelectric substrate 10 is joined to the second piezoelectric substrate 20 or vice versa such that the primary electrodes are connected to each other (namely, the second discontinuity 34 and the third discontinuity 36 are adjoined to each other) and the secondary electrodes are connected each other as illustrated in Figs. 6 and 7, respectively. Accordingly, a first electrode node 42 and a second electrode node 44 are formed, to thereby achieve a multilayer piezoelectric substrate assembly 100.

[0036] The joining of the two piezoelectric substrates can be done by using a silver epoxy adhesive well known in the art. Since the second and the third discontinuities 34 and 36 isolate the electrodes by the comparatively wide gap, an occurrence of a short circuit between the primary electrode and the secondary electrode can be prevented even in case the two piezoelectric substrates are dislocated from each other at the time of joining them.

[0037] After obtaining the multilayer piezoelectric substrate assembly 100, a stapler-shaped thin FPCB(Flexible Printed Circuit Board) 400 for signaling is coupled to the first electrode node 42 on the second main surface of the second piezoelectric substrate 20 and then a backing block 300 is positioned under the FPCB 400 such that a top surface and two opposite side surfaces of the backing block 300 are surrounded by the FPCB 400. The FPCB 400 transmits electric signals to the multilayer piezoelectric substrate assembly 100 and receives ultrasonic signals therefrom. And the backing block 300 functions to absorb the ultrasonic signals to prevent the generation of undesired signals due to the vibration induced by the ultrasonic signals produced by the multilayer piezoelectric substrate assembly 100. In this regard, the FPCB 400 and the backing block 300 may be coupled with each other in advance such that the FPCB 400 surrounds the three surfaces of the backing block 300, and then, the FPCB 400 having the backing block 300 surrounded thereby may be coupled to the first electrode node 42.

[0038] Thereafter, as shown in Fig. 9, a flexible electrode plate 500 for ground is positioned on one of the side surfaces in the vicinity of the first discontinuity 32 and is connected to the second electrode node 44 using a silver epoxy paste 600.

[0039] Subsequently, as illustrated in Fig. 10, an acoustic matching layer 700 is coupled on the first electrode node 42 located on the multilayer piezoelectric substrate assembly 100. The acoustic matching layer 700 has a smaller area than that of the multilayer piezoelectric substrate assembly 100 and is arranged on the multilayer piezoelectric substrate assembly 100 while extending somewhat over the second discontinuity 32. The acoustic matching layer 700 serves to match the piezoelectric substrate assembly 100 with a medium, e.g., a human body, so that ultrasonic signals from the piezoelectric substrate assembly 100 are smoothly propagated toward the medium in a desired direction. Then, the acoustic matching layer 700 is covered with an acoustic lens (not shown), to thereby obtain a multilayer ultrasonic transducer. Here, it is possible to stack two or more acoustic matching layers on top of the multilayer laminated piezoelectric substrate assembly 100.

[0040] Fig. 11 presents a schematic sectional view of the multilayer ultrasonic transducer shown in Fig. 10. The thus obtained multilayer ultrasonic transducer in accordance with the present invention has an advanced vibration feature, so that it can be applied to various equipments such as a medical ultrasonic diagnostic system and a military/ industrial ultrasonic transducer.

[0041] Hereinafter, a preferred embodiment of the present invention will be described in detail. Here, it is to be noted that the present invention is not limited thereto.

Example

[0042] A multilayer ultrasonic transducer in accordance with the preferred embodiment of the present invention was fabricated as follows.

[0043] A <001> single crystalline piezoelectric substrate (PMN-(0.3~0.35)) PT having a thickness of about 0.4 mm to 0.5 mm and a size of about 25 mm to 22 mm x about 15mm to 22mm was prepared (see, Fig. 1). Then, on a first main surface 12, a second main surface 14, a first side surface 16 and a second side surface 18 of the first piezoelectric substrate 10, an electrode layer 12 of an electrical conductive material was deposited with the thickness ranging from about 100 nm to 220 nm (1000Å to 2200Å) by employing an electronic beam deposition method.

[0044] Then, another single crystalline piezoelectric substrate having electrodes formed thereon was fabricated by employing the same method as the above, to thereby obtain a second piezoelectric substrate 20.

[0045] Subsequently, discontinuities 32 and 34 were formed in the electrode layer on the first and the second main surfaces 12 and 14 of the first piezoelectric substrate 10, respectively, by using a dicing saw, so that the electrode layer was divided into two electrodes 22 and 24 isolated from each other (see, Fig. 2). The discontinuities 32 and 34 were formed about 1 mm to 1.5 mm inward spaced away from the second side surface 18 and the first side surface 16 of the first single piezoelectric substrate 10, respectively, and the depth of each discontinuity was made to be about 0.25 mm to 0.35 mm.

[0046] As for the second single piezoelectric substrate 20, a discontinuity 36 was formed in the electrode layer on the first main surface of the second piezoelectric substrate 20 by using the dicing saw, and the electrode layer at the edge portion between the second main surface and the second side surface of the second piezoelectric substrate 20 was removed, so that an edge discontinuity 38 was formed and the electrode layer was divided into two electrodes 26 and 28 (see, Fig. 4). At this time, the discontinuity 36 was formed to have the same shape as that of the discontinuity 34 of the first piezoelectric substrate 10, and the edge discontinuity 38 was formed by abrading the electrode layer at the edge portion between the second main surface and the second side surface of the second piezoelectric substrate 20.

[0047] Afterward, the first and the second piezoelectric substrates 10 and 20 were polarized as illustrated in Figs. 3 and 5, so that the electrodes 22 and 26 were set as primary (minus) electrodes while the electrodes 24 and 28 were configured as secondary (plus) electrodes. Then, the two substrates 10 and 20 were adhered to each other by using a silver epoxy such that the discontinuities 34 and 36 were adjoined to each other while the primary electrodes were joined to each other and the secondary el ectrodes were joined to each other, as shown in Figs. 6 and 7, thereby forming a first and a second electrode nodes 42 and 44. As a result, a laminated piezoelectric single crystalline substrate assembly 100 in accordance with the present invention was achieved.

[0048] Thereafter, as shown in Fig. 8, a top surface of a FPCB 400, to which a first main surface and two opposite side surfaces of the backing block 300 were coupled in advance, was adjoined to the first electrode node 42 located on the second main surface of the second piezoelectric substrate 20 of the multilayer laminated piezoelectric substrate assembly 100.

[0049] Afterward, as shown in Fig. 9, a flexible ground electrode plate 500 is coupled to the second electrode node 44 of the laminated piezoelectric substrate assembly 100 at front side of the first discontinuity 32 using a silver epoxy paste 600. Subsequently, as illustrated in Fig. 10, an acoustic matching layer 700 was formed on the first electrode layer located on the first main surface of the first piezoelectric substrate 10, and then, by covering the acoustic matching layer 700 with an acoustic lens, the multilayer ultrasonic transducer in accordance with the present invention was finally obtained.

Experimental Example

[0050] Pulse-echo characteristics were inspected for each of the multilayer ultrasonic transducer according to the present invention; a PZT (Acuson P2-3AC available from Madison Co. Ltd. in Korea) single-layered transducer (Comparative Example 1) as similar as disclosed in US Patent No. 6,437,487; and a single-layered transducer of a PMN-(0.3-0.35) PT system (Comparative Example 2), and the results were provided in the following Table 1 and in Figs. 9 to 11.

[0051]

Table 1

Properties		ComparativeExamp le 1 (Single-layer PZT)	ComparativeExamp le 2(Single-layer PMN-PT)	PreferredEmbodim ent(MultilayerPM N-PT)
Relative Sensitivity	DB	0	+4.1	+7.8
Central Frequency	MHz	2.85	3.66	4.01
-6dB Bandwidth	%	60.2	107.9	101.0
-22dB Bandwidth	%	98.7	134.7	137.4

[0052] From the table 1, it can be found that the multilayer transducer in accordance with the present invention has a highly improved sensitivity and a larger bandwidth compared to the single-layered PZT or single-layered crystalline piezoelectric transducers.

[0053] Furthermore, by comparing Figs. 9 to 11, the sensitivity of the multilayer piezoelectric transducer in accordance with the present invention is found to be higher than those of the single-layered transducers more than 4dB.

[0054] As described above, the multilayer ultrasonic transducer in accordance with the present invention is fabricated by stacking a plurality of piezoelectric materials while forming electrodes in a novel configuration. Thus, the multilayer ultrasonic transducer has an improved vibration feature, a wide bandwidth and a high sensitivity.

Claims

1. A multilayer piezoelectric substrate assembly (100), comprising:

a first piezoelectric substrate (10) having a first electrode layer formed on a first and a second main surface (12, 14) and a first and a second side surface (16, 18) thereof, the first piezoelectric substrate (10) having a first and a second discontinuity (32, 34) on the first and the second main surface (12, 14) to divide the first electrode layer into a first electrode (22) and a second electrode (24) isolated from each other; and

a second piezoelectric substrate (20) having a second electrode layer formed on a first and a second main surface and a first and a second side surface thereof, the second piezoelectric substrate (20) having a third and a fourth discontinuity (36, 38) to divide the second electrode layer into a third and a fourth electrode (26, 28) isolated from each other, the third discontinuity (36) being formed on the first main surface,

wherein the first and the second piezoelectric substrates (10, 20) are coupled each other such that the second and the third discontinuities (34, 36) are faced each other, to thereby form a first electrode node (42) and a second electrode node (44), the first electrode node (42) having the first and the third electrodes (22, 26) and the second electrode node (44) having the second and the fourth electrodes (24, 28), and

the multilayer piezoelectric substrate assembly (100) being **characterised in that** the fourth discontinuity (38) is formed between the second main surface and the second side surface of the second piezoelectric substrate (20) by abrasion.

2. The multilayer piezoelectric substrate assembly (100) of claim 1, wherein each of the first and the second piezoelectric substrate (10, 20) includes a single crystalline piezoelectric substrate.

3. The multilayer piezoelectric substrate assembly (100) of claim 1, wherein each of the first and the second piezoelectric substrate (10, 20) includes a piezoelectric ceramic substrate.

4. The multilayer piezoelectric substrate assembly (100) of claim 1, wherein each of the first to the third discontinuity (32, 34, 36) is formed to have a depth equivalent to about 70% to 80% of a thickness of a substrate on which said each of the first to the third discontinuity (32, 34, 36) is formed.

5. The multilayer piezoelectric substrate assembly (100) of claim 1, wherein the width of the second discontinuity (34) is larger than that of the first discontinuity (32) and substantially identical to that of the third discontinuity (36).

6. The multilayer piezoelectric substrate assembly (100) of claim 5, wherein the widths of the second and the third discontinuity (34, 36) are set to range from about 0.2 mm to 0.5 mm while the width of the first discontinuity (32) is set to range from about 0.03 mm to 0.1 mm.

7. The multilayer piezoelectric substrate assembly (100) of claim 1, wherein both the first and the second discontinuity (32, 34) are formed about 1 mm to 1.5 mm inward from the first and the second side surface (16, 18) of the first piezoelectric substrate (10), respectively, while the third discontinuity (36) is formed about 1 mm to 1.5 mm inward from the first side surface of the second piezoelectric substrate (20).

8. A multilayer ultrasonic transducer comprising the multilayer piezoelectric substrate assembly (100) of claim 1.

9. The multilayer ultrasonic transducer of claim 8, further comprising:

a flexible printed circuit board (400) coupled to the first electrode node (42);
a backing block (300) surrounded by the flexible printed circuit board (400);
a ground flexible printed circuit board (500) coupled to the second electrode node (44); and
an acoustic matching layer (700) deposited on the multilayer piezoelectric substrate assembly (100).

10. A method for fabricating a multilayer piezoelectric substrate assembly (100) comprising the steps of:

preparing a first and a second piezoelectric substrate (10, 20) having electrode layers of conductive materials deposited on a first and a second main surface (12,14) and a first and a second side surface (16,18) thereof, respectively;
forming a first and a second discontinuity (32, 34) and a third and a fourth discontinuity (36, 38) on the first and second main surface of the first and the second piezoelectric substrates (10, 20) to divide the electrode layers into a first and a second electrode (22, 24) and a third and a fourth electrode (26, 28) isolated from each other, respectively; and
laminating the first and the second piezoelectric substrates (10, 20) on top of each other by allowing the second discontinuity (34) of the first piezoelectric substrate (10) to face the third discontinuity (36) of the second piezoelectric substrate (20), to thereby form a first electrode node (42) having the first and the third electrode (22, 26) being coupled to each other and a second electrode node (44) having the second and the fourth electrode (24, 28) being coupled to each other, and the method for fabricating a multilayer piezoelectric substrate assembly being **characterised in that** the fourth discontinuity (38) is formed between the second main surface and the second side surfaces of the piezoelectric substrate (20) by abrasion.

11. The method of claim 10, further comprising the step of:

polarizing the first and the second substrate (10, 20) to make the first and the second electrode node (42, 44) have different polarity with each other.

12. The method of claim 10, wherein each of the first, the second and the third discontinuities (32, 34, 36) is formed by a dicing saw.

13. A method for fabricating a multilayer ultrasonic transducer including the multilayer piezoelectric substrate assembly (100) fabricated by the method of claim 10.

14. The method of claim 13, further comprising:

coupling a flexible printed circuit board (400) to the first electrode node (42);
coupling a ground flexible printed circuit board (500) to the second electrode node (44): and
forming an acoustic matching layer (700) on the multilayer piezoelectric substrate assembly (100).

Patentansprüche

1. Mehrschichtiger piezoelektrischer Substrataufbau (100), umfassend:

ein erstes piezoelektrisches Substrat (10) mit einer ersten Elektrodenschicht geformt an einer ersten und einer zweiten Hauptoberfläche (12, 14) und einer ersten und einer zweiten Seitenoberfläche (16, 18) derselben, wobei das erste piezoelektrische Substrat (10) eine erste und eine zweite Diskontinuität in der ersten und der zweiten Hauptoberfläche (12, 14) enthält, um die erste Elektrodenschicht in eine erste Elektrode (22) und eine zweite Elektrode zu teilen, die voneinander getrennt sind; und

ein zweites piezoelektrisches Substrat (20) mit einer zweiten Elektrodenschicht geformt an einer ersten und einer zweiten Hauptoberfläche und einer zweiten Seitenoberfläche derselben, wobei das zweite piezoelektrische Substrat (20) eine dritte und eine vierte Diskontinuität (36; 38) enthält, um die zweite Elektrodenschicht in eine dritte und eine vierte Elektrode (26, 28) zu teilen, die voneinander getrennt sind, wobei die dritte Diskontinuität (36) an der ersten Hauptoberfläche geformt ist,
während das erste und das zweite piezoelektrische Substrat (10, 20) aneinander angekoppelt sind, sodass die zweite und die dritte Diskontinuitäten (34, 36) zueinander zugewandt sind, um dadurch einen ersten Elektrodenknoten (42) und einen zweiten Elektrodenknoten (44) zu bilden, wobei der dritte Elektrodenknoten (42) die erste und die dritte Elektroden (22, 26) enthält und der zweite Elektrodenknoten (44) die zweite und die vierte Elektroden (24, 28) enthält und der mehrschichtige piezoelektrische Substrataufbau (100) **dadurch gekennzeichnet ist, dass** die vierte Diskontinuität (38) zwischen der zweiten Hauptoberfläche und der zweiten Seitenoberfläche des zweiten piezoelektrischen Substrats (20) durch Abrasion gebildet wird.

2. Mehrschichtiger piezoelektrischer Substrataufbau (100) nach Anspruch 1, während das erste und das zweite piezoelektrische Substrat (10, 20) ein einziges kristallinisches piezoelektrisches Substrat enthalten.

3. Mehrschichtiger piezoelektrischer Substrataufbau (100) nach Anspruch 1, während das erste und das zweite piezoelektrische Substrat (10, 20) ein piezoelektrisches keramisches Substrat enthalten.

4. Mehrschichtiger piezoelektrischer Substrataufbau (100) nach Anspruch 1, wobei jeweils die erste bis zur dritten Diskontinuität (32, 34, 36) gebildet sind, um eine Tiefe darzustellen, die gleichwertig 70% bis 80% einer Dicke eines Substrates ist, auf welcher jeweils diese erste bis zur dritten Diskontinuität (32, 34, 36) gebildet sind.

5. Mehrschichtiger piezoelektrischer Substrataufbau (100) nach Anspruch 1, wobei die Breite der zweiten Diskontinuität (34) größer ist als diese der ersten Diskontinuität (32) und zwar grundsätzlich identisch der der dritten Diskontinuität (36).

6. Mehrschichtiger piezoelektrischer Substrataufbau (100) nach Anspruch 5, wobei die Breiten der zweiten und der dritten Diskontinuität (34, 36) bestimmt sind, um von ca 0.2 mm bis 0.5 mm zu betragen, während die Breite der ersten Diskontinuität (32) bestimmt ist, um von ca. 0.03 mm bis 0.1 mm zu betragen.

7. Mehrschichtiger piezoelektrischer Substrataufbau (100) nach Anspruch 1, wobei die erste und die zweite Diskontinuität (32, 34) jeweils ca 1 mm bis 1.5 mm nach dem Inneren der ersten und der zweiten Seitenoberfläche (16, 18) jeweils des ersten piezoelektrischen Substrates (10) betragen, während die dritte Diskontinuität (36) ca 1 mm bis 1.5 mm nach dem Inneren der ersten Seitenoberfläche des zweiten piezoelektrischen Substrates (20) beträgt.

8. Mehrschichtiger Ultraschall-Messwandler umfassend den mehrschichtigen piezoelektrischen Substrataufbau (100) nach Anspruch 1.

9. Mehrschichter Ultraschall-Messwandler nach Anspruch 8, ferner bestehend aus:

einer flexiblen Leiterplatte (400), die mit dem ersten Elektrodenknoten (42) gekoppelt ist;
einem Verstärkungsblock (300), der durch die flexible Leiterplatte (400) umschlossen ist;
einer flexiblen Grundleiterplatte (500), die mit dem zweiten Elektrodenknoten (42) gekoppelt ist; und
einer akustischen zusammenpassenden Schicht (700), die auf den mehrschichtigen piezoelektrischen Substrataufbau (100) abgeschieden wird.

10. Verfahren zur Herstellung eines mehrschichtigen piezoelektrischen Substrataufbaus (100),
umfassend die folgenden Schritte:

die Zubereitung eines ersten und eines zweiten piezoelektrischen Substrates (10, 20) mit Elektrodenschichten aus leitfähigen Materialien, die jeweils auf eine erste und eine zweite Hauptoberfläche (12, 14) und eine erste und eine zweite Seitenoberfläche (16, 18) derselben abgeschieden sind,
die Bildung einer ersten und einer zweiten Diskontinuität (32, 34) und einer dritten und einer vierten Diskontinuität (36, 38) an der ersten und der zweiten Hauptoberfläche des ersten und des zweiten piezoelektrischen Substrate (10, 20), um die Elektrodenschichten in eine erste und eine zweite Elektrode (22, 24) und eine dritte und eine vierte Elektrode (26, 28) zu teilen, die voneinander getrennt sind, beziehungsweise; und
die Laminierung des ersten und des zweiten piezoelektrischen Substrate (10, 20) übereinander, wobei die

zweite Diskontinuität (34) des ersten piezoelektrischen Substrate der dritten Diskontinuität (36) des zweiten piezoelektrischen Substrates (20) zugewandt sein kann, um dadurch einen ersten Elektrodenknoten (42), wobei die erste Elektrode und die dritte Elektrode miteinander gekoppelt sind und einen zweiten Elektrodenknoten, wobei die zweite und die vierte Elektroden (24, 28) miteinander gekoppelt sind, zu bilden, und Verfahren zur Herstellung eines mehrschichtigen piezoelektrischen Substrataufbaus, **dadurch gekennzeichnet, dass** die vierte Diskontinuität (38) zwischen der zweiten Hauptoberfläche und der zweiten Seitenoberfläche des zweiten piezoelektrischen Substrats (20) durch Abrasion gebildet wird.

11. Verfahren nach Anspruch 10, ferner umfassend die Stufe der:

Polarisierung des ersten und des zweiten Substrate (10, 20), so dass der erste und der zweite Elektrodenknoten (42, 44) eine unterschiedliche Polarität zueinander aufweisen.

12. Verfahren nach Anspruch 10, wobei die erste, die zweite und die dritte Diskontinuitäten (32, 34, 36) jeweils durch eine Trennsäge gebildet sind.

13. Verfahren zur Herstellung eines mehrschichtigen Ultraschall-Messwandlers, umfassend den mehrschichtigen piezoelektrischen Substrataufbau (100), hergestellt durch das Verfahren des Anspruchs 10.

14. Verfahren nach Anspruch 13, ferner bestehend aus:

der Kupplung einer flexiblen Leiterplatte (400) mit dem ersten Elektrodenknoten (42);
der Kupplung einer flexiblen Grundleiterplatte (500) mit dem zweiten Elektrodenknoten (44) und der Bildung einer akustischen zusammenpassenden Schicht (700) auf den mehrschichtigen piezoelektrischen Substrataufbau (100).

Revendications

1. Ensemble de substrat piézoélectrique multicouches (100), qui comprend :

un premier substrat piézoélectrique (10) ayant une première couche d'électrode formée sur une première et une deuxième surfaces principales (12, 14) et une première et une deuxième surfaces latérales (16, 18) de celui-ci, ledit substrat piézoélectrique (10) ayant une première et une deuxième discontinuités (32, 34) sur lesdites première et deuxième surfaces principales (12, 14) afin de diviser ladite première couche d'électrode en une première électrode (22) et une deuxième électrode (24) isolées l'une de l'autre ; et
un second substrat piézoélectrique (20) ayant une deuxième couche d'électrode formée sur une première et une deuxième surfaces principales et une première et une deuxième surfaces latérales de celui-ci, ledit second substrat piézoélectrique (20) ayant une troisième et une quatrième discontinuités (36, 38) afin de diviser ladite deuxième couche d'électrode en une troisième et une quatrième électrodes (26, 28) isolées l'une de l'autre, ladite troisième discontinuité (36) étant formée sur la première surface principale,
dans lequel lesdits premier et second substrats piézoélectriques (10, 20) sont couplés l'un à l'autre de sorte que lesdites deuxième et troisième discontinuités (34, 36) se fassent face, afin de former un premier noeud d'électrode (42) et un second noeud d'électrode (44), ledit premier noeud d'électrode (42) ayant lesdites première et troisième électrodes (22, 26) et ledit second noeud d'électrode (44) ayant lesdites deuxième et quatrième électrodes (24, 28), et ledit ensemble de substrat piézoélectrique multicouches (100) étant **caractérisé en ce que** ladite quatrième discontinuité (38) est formée entre la deuxième surface principale et la deuxième surface latérale dudit second substrat piézoélectrique (20) par abrasion.

2. Ensemble de substrat piézoélectrique multicouches (100) selon la revendication 1, dans lequel chacun desdits premier et second substrats piézoélectriques (10, 20) comprend un seul substrat piézoélectrique cristallin.

3. Ensemble de substrat piézoélectrique multicouches (100) selon la revendication 1, dans lequel chacun desdits premier et second substrats piézoélectriques (10, 20) comprend un substrat en céramique piézoélectrique.

4. Ensemble de substrat piézoélectrique multicouches (100) selon la revendication 1, dans lequel chacune desdites première à troisième discontinuités (32, 34, 36) est formée de façon à avoir une profondeur équivalente à environ 70% à 80% de l'épaisseur d'un substrat sur lequel chacune desdites première à troisième discontinuités (32, 34,

36) est formée.

5. Ensemble de substrat piézoélectrique multicouches (100) selon la revendication 1, dans lequel la largeur de ladite deuxième discontinuité (34) est supérieure à celle de ladite première discontinuité (32) et sensiblement identique à celle de ladite troisième discontinuité (36).

6. Ensemble de substrat piézoélectrique multicouches (100) selon la revendication 5, dans lequel les largeurs desdites deuxième et troisième discontinuités (34, 36) sont définies comme étant de l'ordre de 0,2 mm à 0,5 mm, alors que la largeur de ladite première discontinuité (32) est définie comme étant de l'ordre d'environ 0,03 mm à 0,1 mm.

7. Ensemble de substrat piézoélectrique multicouches (100) selon la revendication 1, dans lequel lesdites première et deuxième discontinuités (32, 34) sont formées à environ 1 mm à 1,5 mm vers l'intérieur par rapport auxdites première et deuxième surfaces latérales (16, 18) dudit premier substrat piézoélectrique (10), respectivement, alors que ladite troisième discontinuité (36) est formée à environ 1 mm à 1,5 mm vers l'intérieur par rapport à la première surface latérale dudit second substrat piézoélectrique (20).

8. Transducteur à ultrasons multicouches qui comprend l'ensemble de substrat piézoélectrique (100) selon la revendication 1.

9. Transducteur à ultrasons multicouches selon la revendication 8, qui comprend en outre :

   une carte de circuit imprimé flexible (400) reliée audit premier noeud d'électrode (42) ;
   un bloc de support (300) entouré par ladite carte de circuit imprimé flexible (400) ;
   une carte de circuit imprimé flexible de masse (500) reliée audit second noeud d'électrode (44) ; et
   une couche d'adaptation acoustique (700) déposée sur ledit ensemble de substrat piézoélectrique multicouches (100).

10. Procédé de fabrication d'un ensemble de substrat piézoélectrique multicouches (100) qui comprend les étapes consistant à :

   préparer un premier et un second substrats piézoélectriques (10, 20) ayant des couches d'électrode en matériaux conducteurs déposées sur une première et une deuxième surfaces principales (12, 14) et une première et une deuxième surfaces latérales (16, 18) de celui-ci, respectivement ;
   former une première et une deuxième discontinuités (32, 34) et une troisième et une quatrième discontinuités (36, 38) sur lesdites première et deuxième surfaces principales desdits premier et second substrats piézoélectriques (10, 20) afin de diviser lesdites couches d'électrode en une première et une deuxième électrodes (22, 24) et une troisième et une quatrième électrodes (26, 28) isolées l'une de l'autre, respectivement ; et
   laminer lesdits premier et second substrats piézoélectriques (10, 20) l'un sur l'autre en permettant à ladite deuxième discontinuité (34) dudit premier substrat piézoélectrique (10) de faire face à ladite troisième discontinuité (36) dudit second substrat piézoélectrique (20), afin de former un premier noeud d'électrode (42) ayant lesdites première et troisième électrodes (22, 26) reliées l'une à l'autre et un second noeud d'électrode (44) ayant lesdites deuxième et quatrième électrodes (24, 28) reliées l'une à l'autre, et ledit procédé de fabrication d'un ensemble de substrat piézoélectrique multicouches étant **caractérisé en ce que** ladite quatrième discontinuité (38) est formée entre ladite deuxième surface principale et ladite deuxième surface latérale dudit substrat piézoélectrique (20) par abrasion.

11. Procédé selon la revendication 10, qui comprend en outre l'étape consistant à :

   polariser lesdits premier et second substrats (10, 20) afin que lesdits premier et second noeuds d'électrode (42, 44) aient une polarité différente.

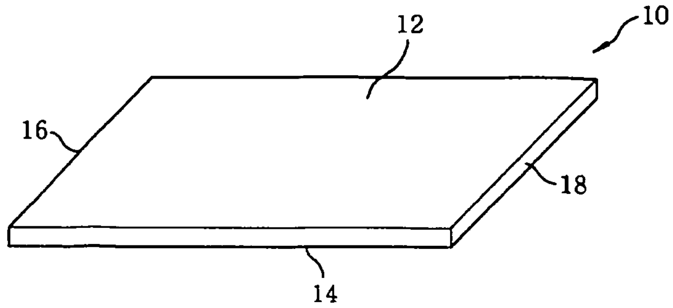
12. Procédé selon la revendication 10, dans lequel chacune desdites première, deuxième et troisième discontinuités (32, 34, 36) est formée par une découpe.

13. Procédé de fabrication d'un transducteur à ultrasons multicouches qui comprend l'ensemble de substrat piézoélectrique multicouches (100) fabriqué avec le procédé selon la revendication 10.

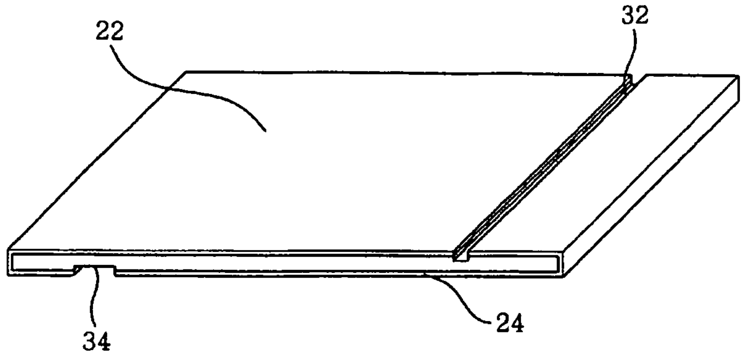
14. Procédé selon la revendication 13, qui comprend en outre :

le couplage d’une carte de circuit imprimé flexible (400) audit premier noeud d’électrode (42) ;
le couplage d’une carte de circuit imprimé flexible de masse (500) audit second noeud d’électrode (44) ; et
la formation d’une couche d’adaptation acoustique (700) sur ledit ensemble de substrat piézoélectrique multi-couches (100).

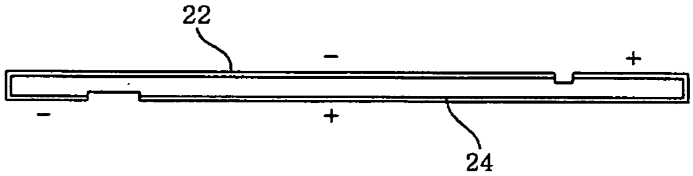
[Fig. 1]



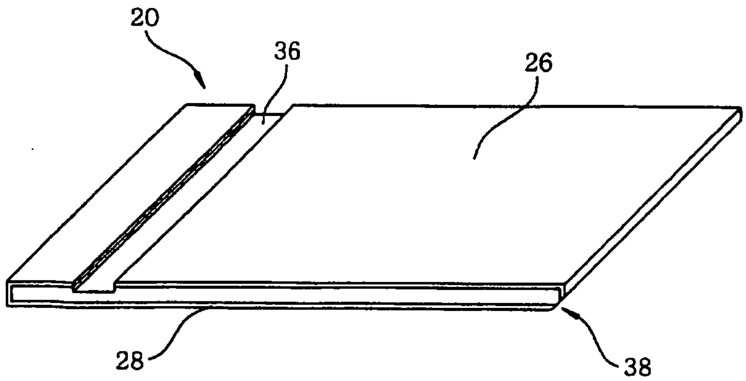
[Fig. 2]



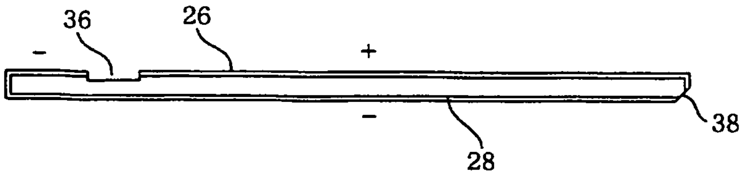
[Fig. 3]



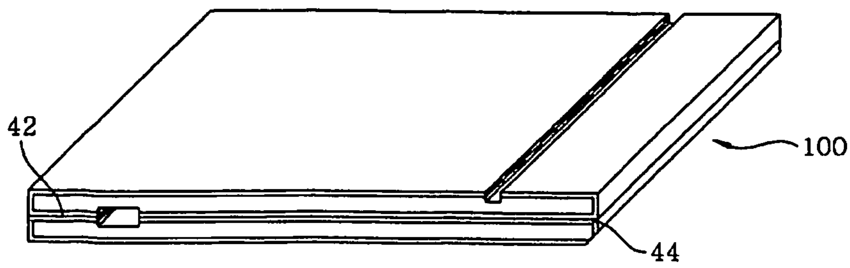
[Fig. 4]



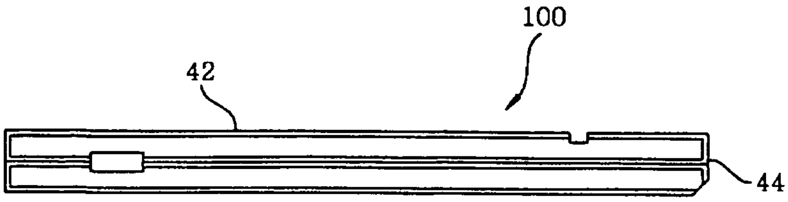
[Fig. 5]



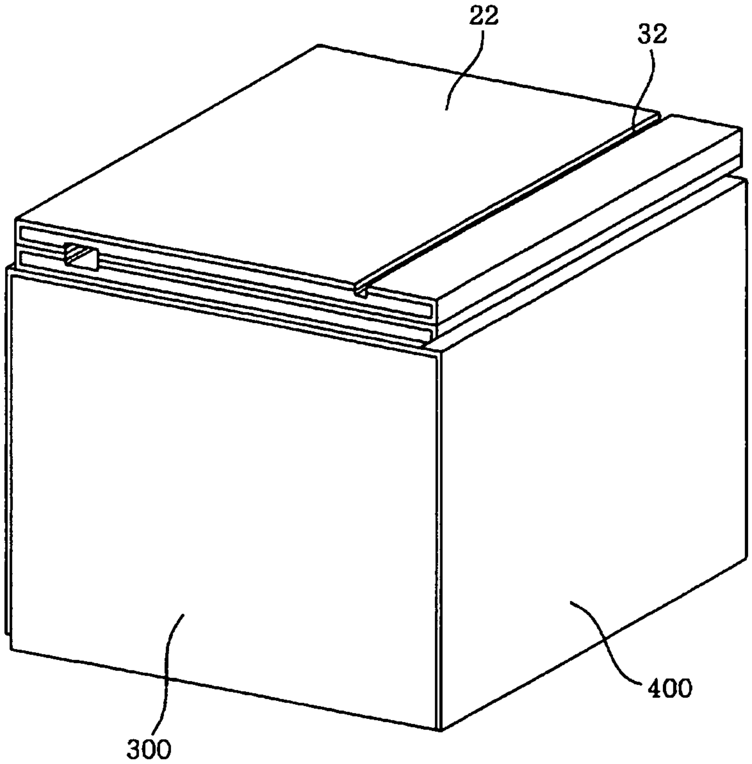
[Fig. 6]



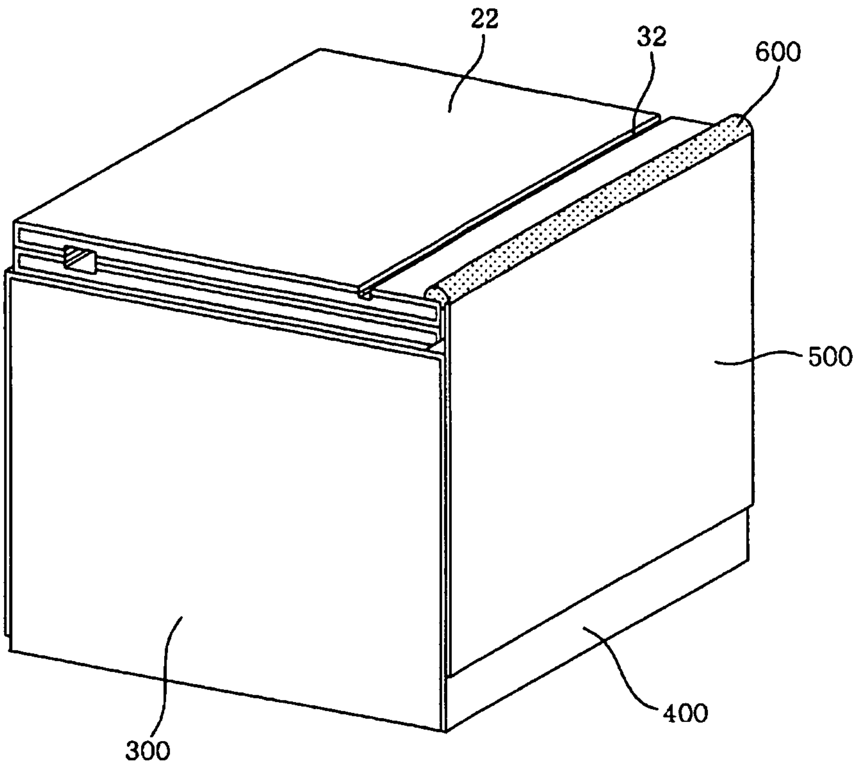
[Fig. 7]



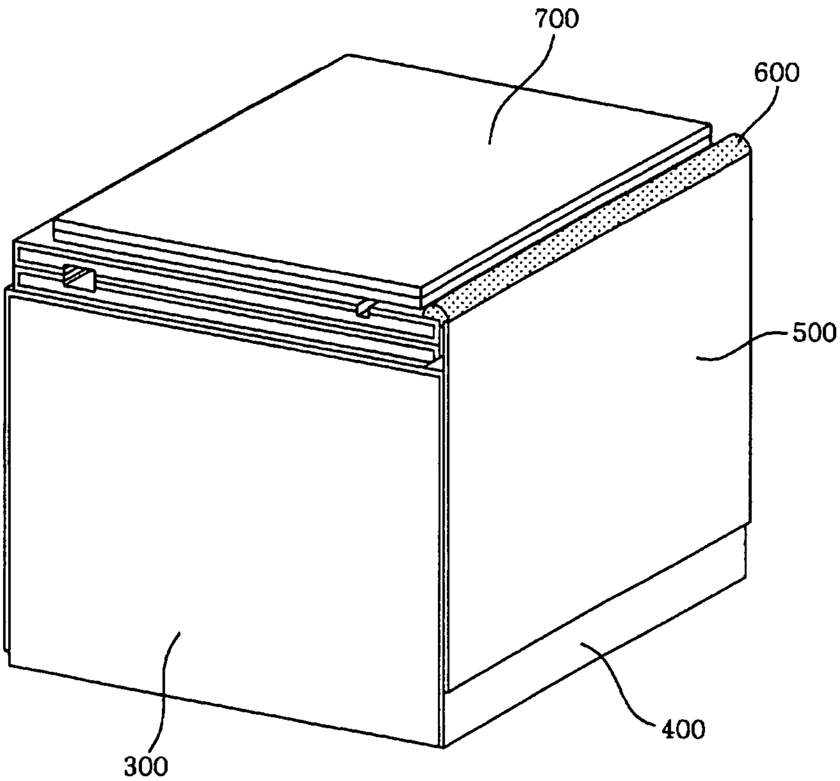
[Fig. 8]



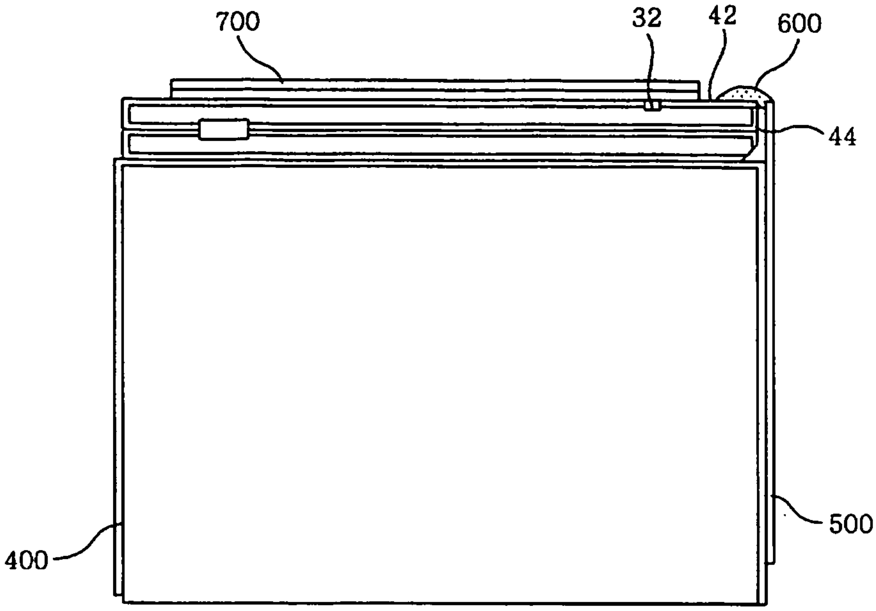
[Fig. 9]



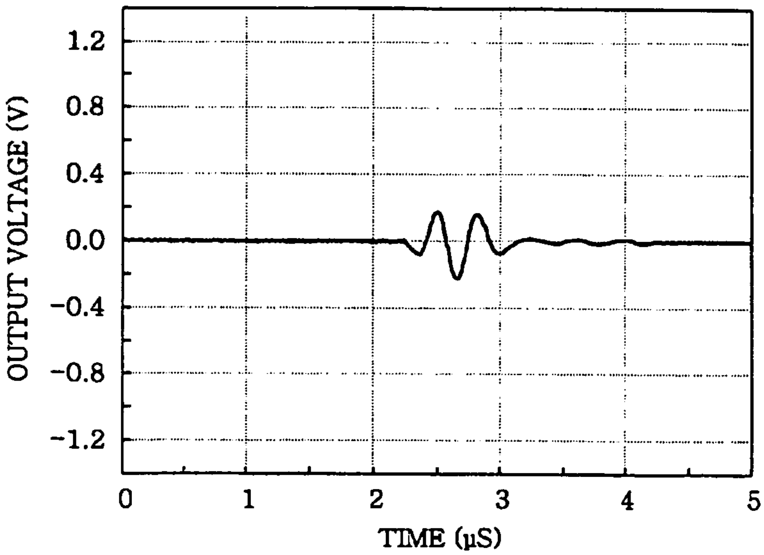
[Fig. 10]



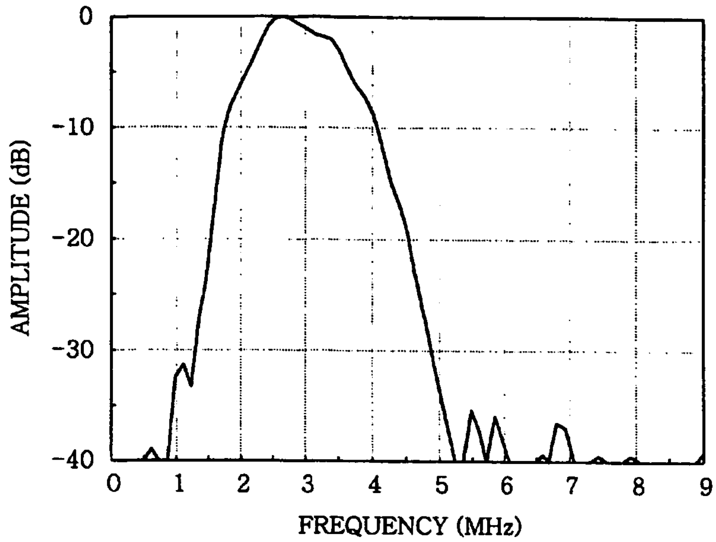
[Fig. 11]


700
32
42
600
44
500
400

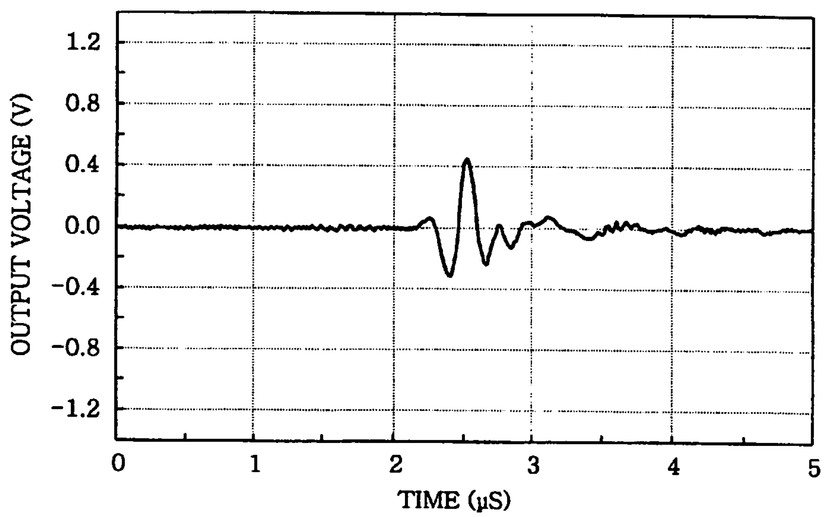
[Fig. 12]


1.2
0.8
0.4
0.0
−0.4
−0.8
−1.2
OUTPUT VOLTAGE (V)
0
1
2
3
4
5
TIME (μS)

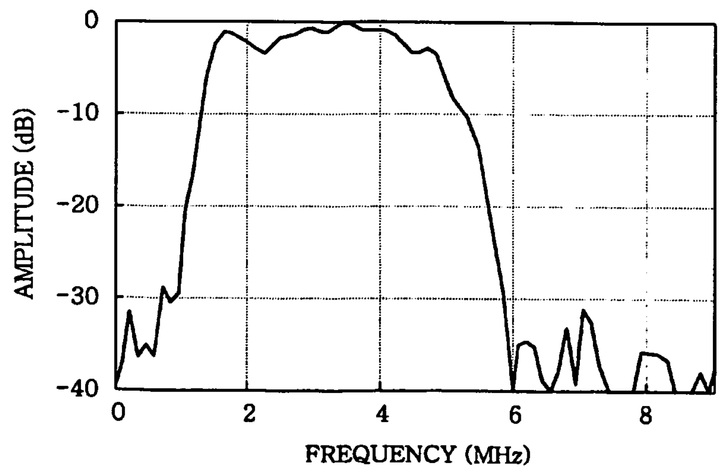
[Fig. 13]



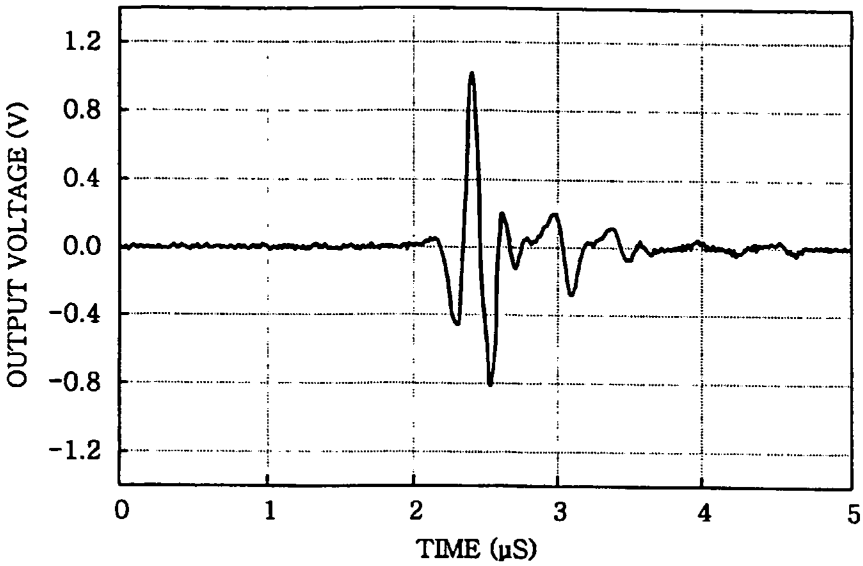
[Fig. 14]



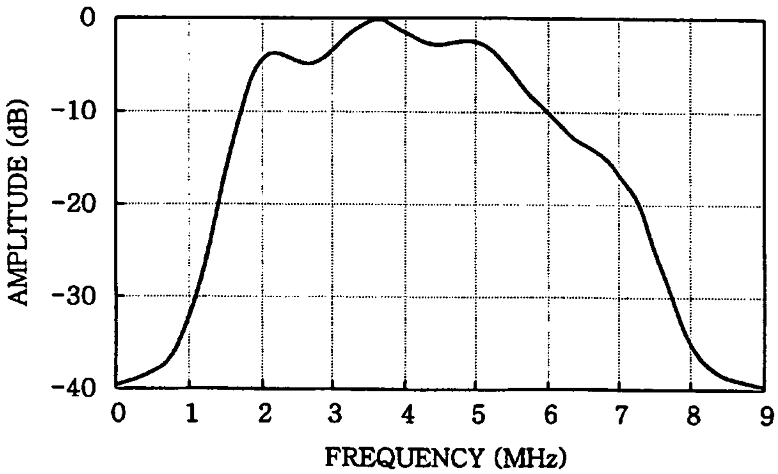
[Fig. 15]



[Fig. 16]


1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2
OUTPUT VOLTAGE (V)
0
1
2
3
4
5
TIME (μS)

[Fig. 17]


0
-10
-20
-30
-40
AMPLITUDE (dB)
0
1
2
3
4
5
6
7
8
9
FREQUENCY (MHz)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 6121718 A **[0007]**
- US 6437487 A **[0007]**
- US 6437487 B **[0050]**

Non-patent literature cited in the description

- **MICHAEL GREENSTEIN ; UMESH KUMAR.** Multilayer piezoelectrical resonators for medical ultrasound transducer. *IEEE Transactions Ultrasonics, Ferroelectrics and Frequency Control,* 1996, vol. 43, 622-624 **[0004]**
- **DAVID M. MILL et al.** Multi-layered PZT-Polymer Composites to increase signal to noise ratio and resolution for medial ultrasound transducer. *IEEE transactions on ultrasonics, ferroelectrics, and frequency control,* July 1999, vol. 46 (4 **[0006]**

专利名称(译)	多层超声换能器及其制造方法		
公开(公告)号	EP1854158B1	公开(公告)日	2013-04-24
申请号	EP2005820704	申请日	2005-12-08
申请(专利权)人(译)	HUMANSCAN CO. , LTD.		
当前申请(专利权)人(译)	HUMANSCAN CO. , LTD.		
[标]发明人	RHIM SUNG MIN C O DONGWON APT 102 501 JUNG HO		
发明人	RHIM, SUNG MIN C/O DONGWON APT. 102-501 JUNG, HO		
IPC分类号	H01L41/047 H01L41/22 B06B1/06 H01L41/083 A61B8/00 H01L41/09 H01L41/18 H01L41/277 H01L41/297 H04R17/00 H04R31/00		
CPC分类号	H01L41/27 B06B1/0611 H01L41/0471 H01L41/0475 H01L41/083 Y10T29/42 Y10T29/49005		
优先权	1020050014314 2005-02-22 KR		
其他公开文献	EP1854158A4 EP1854158A1		
外部链接	Espacenet		

摘要(译)

一种多层超声换能器，包括层叠有第一和第二压电基板的多层压电基板组件（100），所述第一和第二压电基板彼此叠置，并且具有第一电极节点（42）和第二电极（44）节点，所述第一电极节点（42）和第二电极（和辅助电极，分别是连接到第一电极节点的柔性印刷电路板，具有由柔性印刷电路板围绕的预定厚度的背衬块，连接到第二电极节点的接地柔性印刷电路板，以及声学沉积在多层压电基片组件上的匹配层。

$$V(N)=V(1)/N$$