US008330333B2

(12) **United States Patent**
Harhen et al.

(10) **Patent No.: US 8,330,333 B2**
(45) **Date of Patent: Dec. 11, 2012**

(54) ULTRASOUND IMAGING TRANSDUCER ACOUSTIC STACK WITH INTEGRAL ELECTRICAL CONNECTIONS

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **12/845,480**

(22) Filed: **Jul. 28, 2010**

(65) **Prior Publication Data**

US 2011/0025172 A1 Feb. 3, 2011

Related U.S. Application Data

(60) Provisional application No. 61/229,480, filed on Jul. 29, 2009.

(51) **Int. Cl.**
H01L 41/09 (2006.01)
A61B 8/00 (2006.01)

(52) **U.S. Cl.** **310/334**; 310/322; 310/326; 310/327; 600/459

(58) **Field of Classification Search** 310/316.01, 310/322, 326, 327, 334; 600/459
See application file for complete search history.

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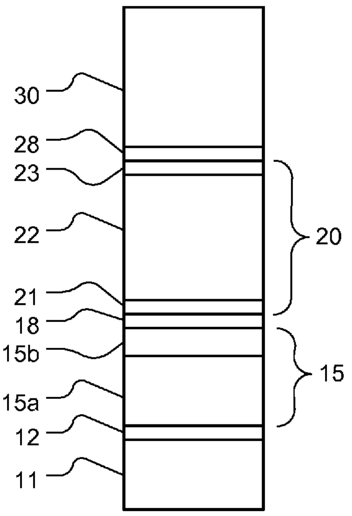
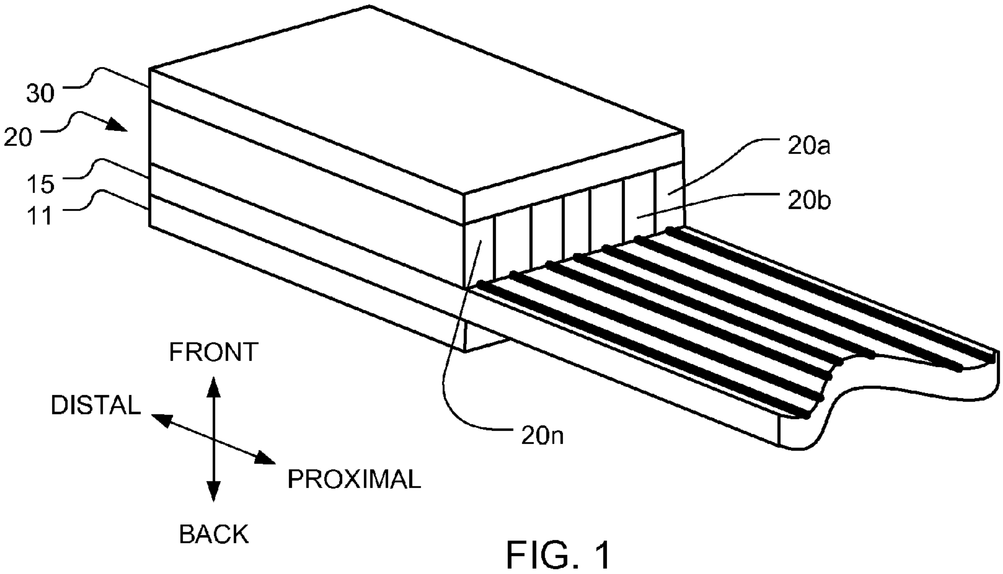
(57) **ABSTRACT**

An ultrasound transducer that includes a backing layer, an insulating layer disposed on top of the backing layer, and a plurality of conductive traces disposed on top of the insulating layer are disclosed. Each of the conductive traces has an upper face. A plurality of transducer elements, each having (a) a core of piezoelectric material and (b) a conductive coating disposed beneath the core, are bonded directly to the upper face of a respective one of the plurality of conductive traces. Methods for fabricating ultrasound transducers are also disclosed.

13 Claims, 3 Drawing Sheets

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20
15
11
20a
20b
20n
FRONT
DISTAL
PROXIMAL
BACK

FIG. 1

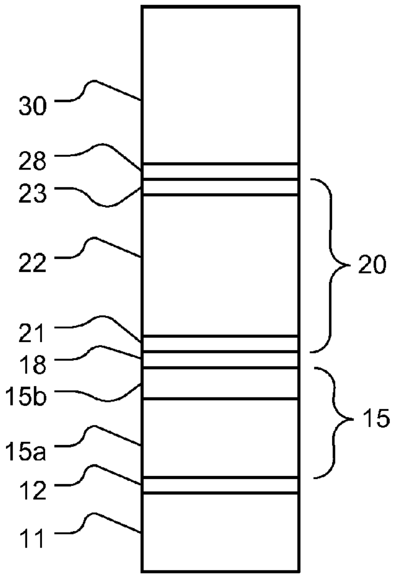
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FIG. 2

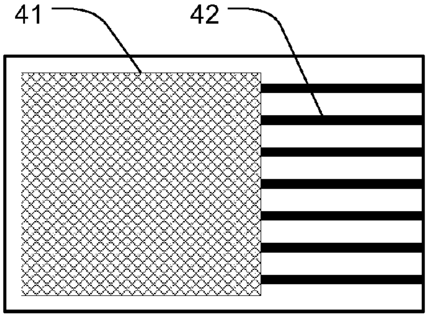


FIG. 3A

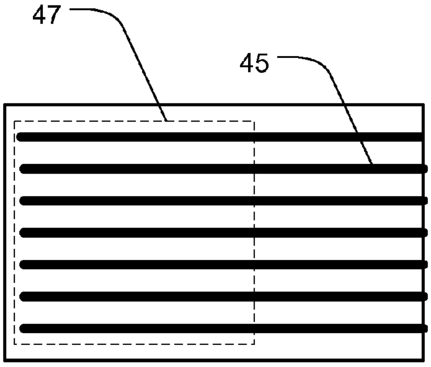


FIG. 4

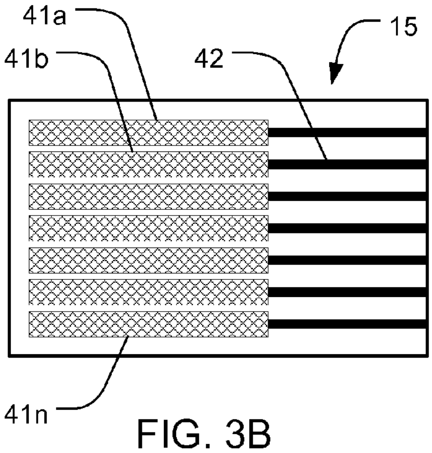


FIG. 3B

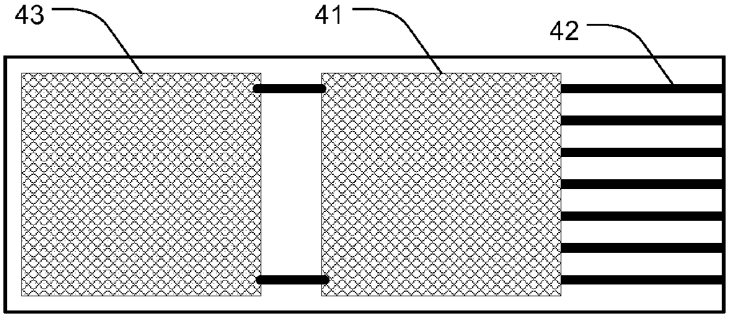
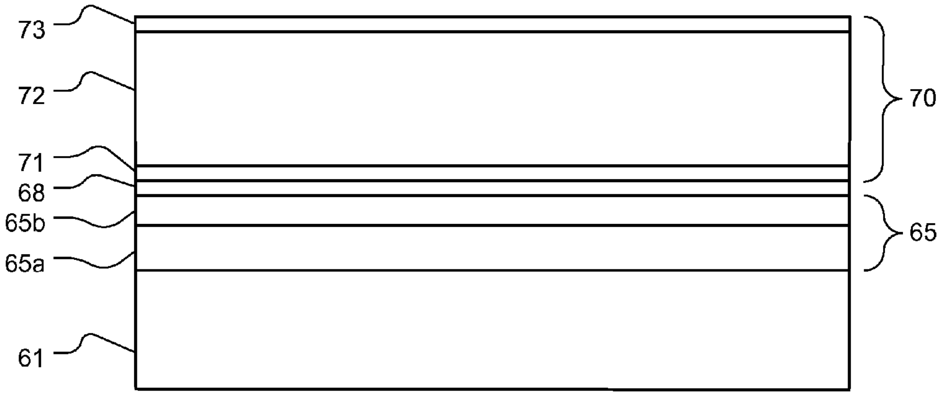


FIG. 3C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72
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65b
65a
61
70
65

FIG. 5A

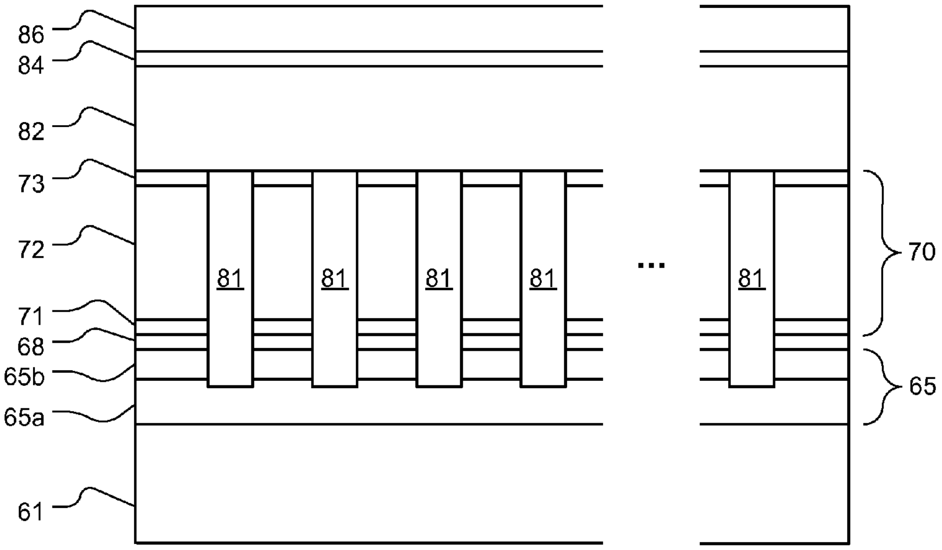
86
84
82
73
72
71
68
65b
65a
61
81
81
81
81
...
81
70
65

FIG. 5B

ULTRASOUND IMAGING TRANSDUCER ACOUSTIC STACK WITH INTEGRAL ELECTRICAL CONNECTIONS

CROSS REFERENCE TO RELATED APPLICATIONS

This Application claims the benefit of U.S. Provisional Application 61/229,480, filed Jul. 29, 2009, which is incorporated herein by reference.

BACKGROUND

Transesophageal echocardiography (TEE) is an ultrasound imaging technique that provides images of the heart for diagnostic and/or monitoring purposes. One particularly beneficial use of TEE is for obtaining images of the transgastric short axis view (TGSAV) of the left ventricle (LV). This is particularly useful for managing the cardiac function of patients in several hospital settings including the Intensive Care Unit and the Post Operative Setting. Small TEE probes that can be used over an extended period of time are particularly useful in this difficult patient population, as described in application Ser. No. 10/996,816, which us incorporated herein by reference as if set forth in its entirety.

Manufactures of conventional TEE ultrasound transducers typically strive to acoustically isolate the electrical connections to the piezo-electric components from the piezo materials and the associated backing and matching layers (also known as the acoustic stack). This isolation is desirable due to the deleterious effect that the materials typically employed have on the tuning of the acoustic stack. Some conventional approaches for making the electrical connection while maintaining acoustic isolation include special edge bonding, wire bonding, special ceramic fingers, and other high cost, high precision methods. Other approaches include using very fine wire attachments that go through the backing layers, aligned so that they are effectively in between the elements, where they do not affect the acoustic stack. Unfortunately, all these approaches for making the electrical connection are relatively difficult and/or expensive.

BRIEF SUMMARY OF THE INVENTION

One aspect of the invention relates to an ultrasound transducer that includes a backing layer, an insulating layer disposed on top of the backing layer, and a plurality of conductive traces disposed on top of the insulating layer. Each of the conductive traces has an upper face. A plurality of transducer elements, each having (a) a core of piezoelectric material and (b) a conductive coating disposed beneath the core, are bonded directly to the upper face of a respective one of the plurality of conductive traces. Preferably, a matching layer is disposed on top of the plurality of transducer elements.

Another aspect of the invention relates to a method of fabricating an ultrasound transducer. This method includes the steps of bonding a block of piezoelectric material having a conductive coating to a flex circuit having (a) a first conductive region disposed on an insulating substrate and (b) at least 20 conductive traces that are disposed on the insulating substrate and are in electrical contact with the first conductive region, so that the block bonds to the first conductive region. The block is then diced into at least 20 transducer elements. The dicing step is controlled so as to cut all the way through the block and all the way through the first conductive region, and part way through, but not completely through, the insulating substrate, and the dicing is performed at positions that are aligned with respect to the conductive traces so that after the dicing step is implemented, (a) the first conductive region is divided into at least 20 regions that are electrically isolated from each other, and (b) each of the at least 20 regions is in electrical contact with a respective one of the at least 20 conductive traces.

Another aspect of the invention relates to a method of fabricating an ultrasound transducer. This method includes the steps of bonding a block of piezoelectric material having a conductive coating to a flex circuit having at least 20 parallel conductive traces disposed on an insulating substrate, so that that the block bonds with a distal end of the at least 20 conductive traces. The block is then diced into at least 20 transducer elements. The dicing is controlled so as to cut all the way through the block and part way through, but not completely through, the insulating substrate. The dicing is performed at positions that are aligned with respect to the conductive traces so that after the dicing step is implemented, the at least 20 transducer elements are electrically isolated from each other, with each of the at least 20 transducer elements bonded to a respective one of the at least 20 conductive traces.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of the layers that form the acoustic stack in an embodiment of the invention.

FIG. **2** is a more detailed view of the layers that form the acoustic stack structure in the FIG. **1** embodiment.

FIG. **3**A is an initial configuration of a flex circuit that can be used to form the acoustic stack structure shown in FIG. **1**.

FIG. **3**B is a final configuration for the flex circuit of FIG. **3**A.

FIG. **3**C is an initial configuration of the flex circuit of FIG. **3**A, with an extra patch that is used to form a ground plane.

FIG. **4** is another initial configuration of a flex circuit that can be used to form the acoustic stack structure shown in FIG. **1**.

FIG. **5**A is a cross section of another embodiment of an acoustic stack in the middle of the manufacturing process.

FIG. **5**B is a cross section of the FIG. **5**A embodiment after it has been completed.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** depicts a first preferred embodiment of the invention in which the electrical interface is specifically included as part of the backing section of the tuned acoustic stack structure. This structure of this embodiment can be divided into four groups. Beginning with the back (also referred to herein as the bottom), those groups are: a backing substrate **11**, a flex circuit **15**, a piezoelectric section **20**, and finally a matching layer **30** in front (also referred to herein as the top). Note that while FIG. **1** shows a schematic representation of seven elements **20***a* . . . **20***n* in the piezoelectric section **20**, a larger number of elements (e.g., between 20 and 80) is preferred. For example, some preferred sizes for TEE applications include between 24 and 40 elements for use in miniature probes, and between 60 and 70 elements for use in full size probes. Note also that the figures in this application are not drawn to scale.

FIG. **2** shows more details of the FIG. **1** embodiment. The back layer is the backing substrate **11**, which can be made of any material that is an effective acoustic absorber in the frequency range of interest, e.g., from 4.5 to 7.5 MHz. An epoxy/tungsten matrix is one suitable material. Others suitable materials include tuned structures of high and low acoustic impedance materials that can be configured to be absorbers by destructive interference within the desired frequency range. These materials are preferably chosen to minimize any negative effects due to this construction method (e.g., regions of poor sensitivity within the desired frequency range, excessive heating due to poor thermal heat transfer, or being difficult to manufacture). The thickness of the backing substrate **11** is not critical as long as unwanted components of ultrasound energy are not reflected back into the PZT.

A flex circuit **15** is mounted on the backing substrate **11**. The flex circuit **15** has an insulating layer **15***a* in the back and a conductive layer **15***b* in front. Preferably, the insulating layer **15***a* is made of polyimide, or another material that is monolithic, flexible, has uniform thickness, and is easy to use in conventional, well-understood manufacturing processes. Preferably, the conductive layer **15***b* insulating is made of copper or another suitable metal that is monolithic, has uniform thickness, and may be further processed with conventional, well-understood manufacturing processes. In less preferred embodiments, a non-metallic conductive layer may be used instead of copper. Mounting of the flex circuit **15** onto the backing substrate **11** may be done using a suitable adhesive **12** like EPO-TEK® 301, by applying an epoxy-based backing in liquid form directly onto the polyimide, and letting it cure.

The thickness of the copper and polyimide utilized in the construction of the flex circuit are chosen to either (a) have minimal impact on the rest of the resonant structure, in which case they are made as thin as practical, or (b) the thicknesses are chosen as to allow transmission of the ultrasound into a backing structure which incorporates the flex circuit as the initial layers of said backing structure. The former approach has been utilized in some preferred embodiments by (1) keeping the thickness of both the polyimide and the copper well below ¼ wavelength at the frequency of interest, (2) making the copper thick enough to have a low resistance, and (3) making the polyimide thick enough to facilitate manufacturability of the flex circuits on conventional equipment using conventional processes. A 25 μm layer of polyimide and a 17.5 μm layer of copper have been found to work well.

After the flex circuit **15** is mounted on the backing substrate **11**, the mounted portion of the insulating layer **15***a* is substantially flat and the conductive layer **15***b* remains exposed on the front face of the flex circuit **15**. The piezoelectric section **20** is then bonded directly to the exposed conductive layer **15***b* using, for example, a conductive adhesive **18** such as Tracon Silver epoxy. Very low melting point solders available from Indium Corporation may also be used to bond the piezoelectric section **20** to the conductive layer **15***b* by placing the solder between the layers in foil or paste form, then melting the solder to form a joint. When a conductive bonding method is used, an electrical interface between the conductive layer **15***b* of the flex circuit **15** and the piezoelectric section **20** is established by conduction. Alternatively, the piezoelectric section **20** may be bonded directly to the exposed conductive layer **15***b* using an epoxy adhesive like EPO-TEK® 301, or another suitable insulating adhesive. When an insulating adhesive is used, an electrical interface between the conductive layer **15***b* of the flex circuit **15** and the piezoelectric section **20** is established by capacitive coupling.

The piezoelectric section **20** is preferable made from a PZT material **22** that has been coated on the front and back with layers **23**, **21** of a conductive material like silver or gold. In alternative embodiments, one or both of those layers can be omitted, in which case appropriate modifications to the construction may be required (e.g., using a different adhesive **18**), as will be appreciated by persons skilled in the relevant arts.

A number of alternative approaches may be used for the next step in the fabrication process. In one embodiment, the piezoelectric section **20** starts out as a block of material (i.e., it is not pre-diced into individual elements). The portion of the flex circuit **15** that goes beneath the piezoelectric section **20** initially starts out as a continuous region of copper, and the portion of the flex circuit that is not beneath the piezoelectric section **20** has a plurality of conductive traces that terminate at that continuous region of copper. This initial configuration for the flex circuit **15** is shown in FIG. **3**A, with the continuous region of copper **41** and the traces **42**.

Returning to FIGS. **1** and **2**, after the piezoelectric section **20** is bonded to the continuous region of copper, the piezoelectric section **20** is diced into individual elements using a dicing saw. The depth of the dicing is accurately controlled so as to (a) cut through the whole piezoelectric section **20**, and (b) also cut through the whole conductive layer **15***b*, but not deep enough to cut completely through the rear insulating layer **15***a* of the flex circuit **15**. This forms an array of individual PZT elements **20***a* . . . **20***n*, each of which is electrically interfaced to its own individual, electrically isolated, section of the flex circuit **41***a* . . . **41***n* (as shown in FIG. 3B). The cuts are preferably parallel to the conductive traces at a pitch that matches the pitch of the conductive traces, with the cuts aligned so that each of these newly divided individual sections of the flex circuit **41***a* . . . **41***n* lines up with one of the conductive traces **42**, resulting in an electrical connection (i.e., a trace on the flex circuit **15**) for each individual PZT element **20***a* . . . **20***n* (shown in FIG. **1**).

In a second embodiment, the piezoelectric section **20** starts out as a block of material (i.e., it is not pre-diced into individual elements), but the portion of the flex circuit **15** that goes beneath the piezoelectric section **20** starts out pre-divided, in the form of a plurality of traces that extend out to the portion of the flex circuit that is not beneath the piezoelectric section **20**. This configuration for the flex circuit **15** is shown in FIG. **4**, with the plurality of traces **45**. The piezoelectric section **20** is bonded to the distal end of the traces, in the region indicated by dashed line **47**. Returning to FIGS. **1** and **2**, after the bonding, the piezoelectric section **20** is diced into individual elements using a dicing saw. In this embodiment, the depth of the dicing is accurately controlled to cut through the whole piezoelectric section **20**, but not deep enough to cut completely through the rear insulating layer **15***a* of the flex circuit **15**. This results in a plurality if individual PZT elements **20***a* . . . **20***n*, each of which is electrically interfaced to its own trace on the flex circuit. The cuts are preferably parallel to the conductive traces at a pitch that matches the pitch of the conductive traces, with the cuts aligned so that the cuts will lie between the traces **45** (shown in FIG. **4**). This results in an electrical connection (i.e., a trace on the flex circuit **15**) for each PZT element.

In a third embodiment, the piezoelectric section **20** starts out pre-diced into individual elements **20***a* . . . **20***n*, and the portion of the flex circuit **15** that goes beneath the piezoelectric section **20** also starts out pre-divided, as shown in FIG. **4**. The piezoelectric section **20** (shown in FIG. **1**) is bonded to the distal end of the traces, in the region indicated by dashed line **47** in FIG. **4**, taking care to align the individual elements **20***a* . . . **20***n* of the piezoelectric section **20** with the traces on the flex circuit **15**. This also results in a plurality of individual PZT elements **20***a* . . . **20***n*, each of which is electrically interfaced to its own trace on the flex circuit.

Note that in the above-described embodiments, when a conductive bonding method between piezoelectric section **20** and the conductive layer **15***b* of the flex circuit **15** is used, the electrical interface between each trace and the corresponding transducer element is a conductive interface. In this situation, an electrical signal that is applied to a given conductive trace will travel along the trace, cross the conductive bonding material via conduction, and arrive at the corresponding transducer element. Similarly, return signals that are generated by each transducer element will travel across the conductive bonding material by conduction, and arrive at the corresponding conductive trace. When an insulating bonding method between piezoelectric section **20** the conductive layer **15***b* of the flex circuit **15** is used, the electrical interface between each trace and the corresponding transducer element is a capacitive coupling interface. In this situation, an AC electrical signal that is applied to a given conductive trace will travel along the trace, travel across the insulating bonding material by capacitive coupling, and arrive at the corresponding transducer element. Similarly, return signals that are generated by each transducer element will travel across the insulating bonding material by capacitive coupling, and arrive at the corresponding conductive trace.

A ground plane may be implemented by using the conductive layer **23** on the front face of the piezoelectric section **20**. Since the conductive layer **23** is divided into strips, an electrical connection is preferably made between those strips. In some preferred embodiments, the transducer elements at either lateral side (i.e., elements **20***a* and **20***n* shown in FIG. **1**) are guard elements that do not transmit ultrasound. In these embodiments, the conductive traces in the flex circuit **15** below those elements are available to make a connection to the ground plane. One suitable way to make the electrical connection between the traces beneath the side elements and the conductive strips on the front face of the piezoelectric section **20** is with a conductive epoxy (e.g., silver epoxy), which may be applied at either the distal wall or the proximal wall of the piezoelectric section **20**.

After the piezoelectric section **20** is added as described above, a material that supports the PZT elements mechanically but does not transfer ultrasound between the elements with any degree of effectiveness is preferably backfilled into the gaps between the elements. Examples of suitable materials include silicone and polyurethane. Next, a matching layer **30** is mounted on top of the piezoelectric section **20** using a wide range of adhesives **28** such as epoxies, pressure sensitive adhesives, multi-part silicones, urethanes, or another adhesive that will not damage the transducer as built up to this point. In alternative embodiments, the matching layer **30** may be applied as a liquid and cured (e.g., using UV light).

In alternative embodiments, the matching layer **30** may be mounted on top of the piezoelectric section **20** prior to dicing, in which case the dicing and backfilling steps would be performed after the step of mounting the matching layer **30** on the piezoelectric section **20**.

Alternative ways to implement a ground plane on the front of the piezoelectric section **20** may be used. One way is to mount a piece of conductive foil on top of the piezoelectric section **20**. Another way is to implement the ground plane using the same flex circuit **15** that sits beneath the piezoelectric section **20**. This may be accomplished by using a large conductive patch **43** that starts out positioned laterally offset with respect to the patch **41**, as shown in FIG. **3**C. After the piezoelectric section **20** is mounted on top of the patch **41** and diced into individual elements as discussed above, the large conductive patch **43** is then folded up and then over the front face of the piezoelectric section **20** to form a roof that serves as the ground plane.

FIGS. **5**A and **5**B depict another preferred embodiment of an acoustic stack. More specifically, FIG. **5**A is a cross section of this embodiment in the middle of the manufacturing process, and FIG. **5**B is a cross section of this embodiment after it has been completed. Starting with FIG. **5**A, the lowermost layer **61** is the backing layer made of a tungsten filled epoxy mixed to produce a matrix of Acoustic Impedance of 2.7 MRayls, greater than 840 μm thick. A flex circuit **65** is mounted on top of the backing layer. The flex circuit has a lower layer **65***a* of polyimide 25 μm thick, with a ½ ounce layer **65***b* of copper (i.e., a 17.5 μm layer of Cu) disposed on top of the polyimide layer **65***a*. One suitable way to attach the backing layer **61** to the polyimide layer **65***a* of the flex circuit **65** is to flip the flex circuit upside down so the polyimide layer **65***a* is on top, apply the epoxy in liquid form on top of the polyimide, wait for it to cure, grind the epoxy backing layer **61** down to the desired thickness, and then flip everything over so the flex circuit is right side up.

A piezoelectric block **70** made of a 280 μm thick piece of PZT-5H **72** with silver electrodes **71**, **73** coated on both its front and rear face is then bonded directly to top of the copper side of the flex circuit **65**, using a thin layer **68** (preferably less than 10 μm thick) of EPO-TEK® 301 epoxy adhesive (made by Epoxy Technology, Inc.) or an suitable alternative like Spurrs epoxy. Preferably, the bonding material **68** is so thin that its impact on the acoustic characteristics of the stack becomes negligible. In alternative embodiments, different thicknesses for the piezoelectric block may be used, e.g., between 150 and 400 μm.

Turning now to FIG. **5**B, the piezoelectric block **70** is then diced as described above, so that the dicing cuts all the way through the piezoelectric block and part way through, but not all the way through, the insulating layer **65***a* of the flex circuit **65**. For example, the transducer may be divided into 32 active elements, spaced at a pitch of 140 micrometers. Of course, a different number of active elements may be used, as explained above. Different dicing pitches may also be used (e.g., pitches between 100 and 200 μm), depending on the desired operating frequency. After dicing, the spaces between the elements of the transducer are preferably filled in with a soft elastomer material **81** (e.g., silicone).

A matching layer is then disposed on top of the piezoelectric block **70**. One suitable matching layer consists of (from the bottom to the top): A layer **82** of Alumina filled epoxy mixed to produce a matrix with Acoustic Impedance of 5.0 MRayls, 75-80 μm thick; a layer **84** of EPO-TEK® 301 adhesive, preferably less than 10 μm thick; and a layer **86** of polyurethane 100-105 μm thick, of Acoustic Impedance 1.9 MRayls.

Note that it may be possible to change the assembly steps in this embodiment, and still end up with the same acoustic stack. Various substitutions may also be made to arrive at similar configurations, or at alternative configurations that will perform well enough to function in the intended application.

The techniques described above make it possible to make the electrical interface to the individual elements in ultrasound transducers, and provide high performance at a significantly lower cost as compared to conventional techniques.

While the present invention has been disclosed with reference to certain embodiments, numerous modifications, alterations, and changes to the described embodiments are possible without departing from the sphere and scope of the present invention, as defined in the appended claims. Accordingly, it is intended that the present invention not be limited to the described embodiments, but that it has the full scope defined by the language of the following claims, and equivalents thereof.

What is claimed is:

1. An ultrasound transducer comprising:

a layer of insulating material, the layer having an upper face;

a backing layer disposed beneath the layer of insulating material;

a plurality of conductive traces disposed on the upper face of the layer of insulating material, each of the conductive traces having an upper face;

a plurality of transducer elements, each of the transducer elements having (a) a core of piezoelectric material and (b) a conductive coating disposed beneath the core, the conductive coating having a lower face; and

a matching layer disposed on top of the transducer elements,

wherein the lower face of each of the transducer elements is bonded directly to the upper face of a respective one of the plurality of conductive traces, and

wherein the layer of insulating material is substantially flat.

2. The transducer of claim **1**, wherein the lower face of each of the transducer elements is bonded directly to an upper face of a respective one of the plurality of conductive traces using an insulating adhesive.

3. The transducer of claim **1**, wherein the lower face of each of the transducer elements is bonded directly to an upper face of a respective one of the plurality of conductive traces using a conductive adhesive.

4. The transducer of claim **1**, wherein the lower face of each of the transducer elements is bonded directly to an upper face of a respective one of the plurality of conductive traces by soldering.

5. The transducer of claim **1**, wherein the piezoelectric material comprises PZT.

6. The transducer of claim **1**, wherein the plurality of transducer elements comprises at least 20 transducer elements, the plurality of conductive traces comprises at least 20 conductive traces, the transducer elements are spaced at a pitch between 100 and 200 μm, and the transducer elements are between 150 and 400 μm thick.

7. The transducer of claim **6**, wherein the lower face of each of the transducer elements is bonded directly to an upper face of a respective one of the plurality of conductive traces using an insulating adhesive.

8. The transducer of claim **1**, wherein a thickness of the layer of insulating material is below ¼ wavelength at an operating frequency of the transducer, and wherein a thickness of the conductive traces is below ¼ wavelength at the operating frequency.

9. The transducer of claim **1**, wherein the layer of insulating material is about 25 μm thick.

10. The transducer of claim **9**, wherein the layer of insulating material is polyimide.

11. The transducer of claim **1**, wherein the conductive traces are about 17.5 μm thick.

12. The transducer of claim **11**, wherein the conductive traces are copper.

13. The transducer of claim **1**, wherein the layer of insulating material is polyimide and is about 25 μm thick, and wherein the conductive traces are copper and are about 17.5 μm thick.

* * * * *

专利名称(译)	超声成像换能器声学堆栈与整体电气连接		
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申请号	US12/845480	申请日	2010-07-28
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优先权	61/229480 2009-07-29 US		
其他公开文献	US20110025172A1		
外部链接	Espacenet　USPTO		

摘要(译)

公开了一种超声换能器，其包括背衬层，设置在背衬层顶部上的绝缘层，以及设置在绝缘层顶部上的多个导电迹线。每个导电迹线具有上表面。每个具有（a）压电材料芯和（b）设置在芯下方的导电涂层的多个换能器元件直接结合到多个导电迹线中的相应一个的上表面。还公开了制造超声换能器的方法。