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(54) **ULTRASOUND ENDOSCOPE AND METHODS OF MANUFACTURE THEREOF**

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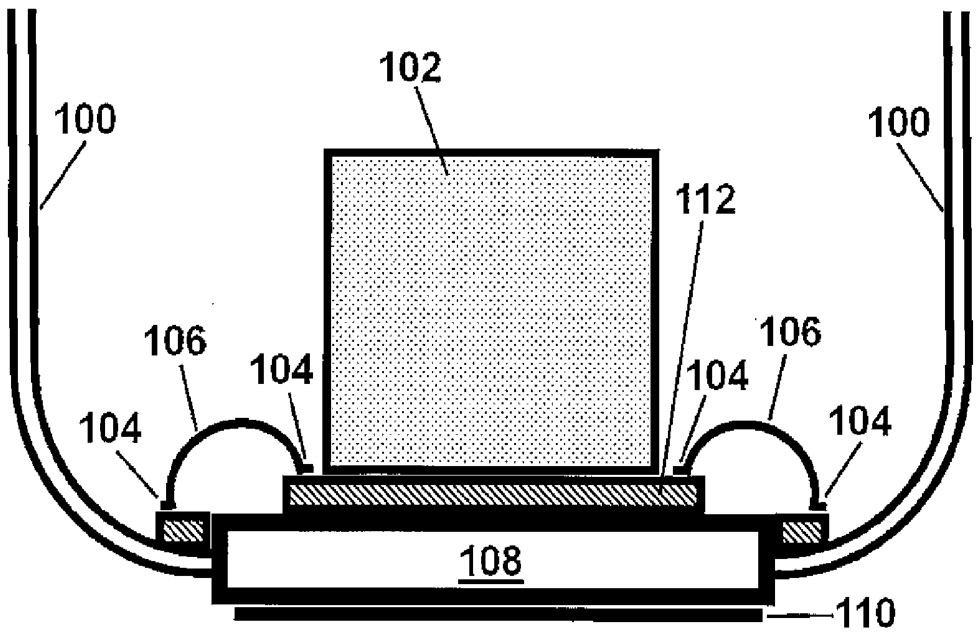
(57) **ABSTRACT**

To address limitations of conventional transducers, a phased array transducer is provided with a form factor suitable o for packaging into, e.g., an endoscope. A method of manufacture of small packaging transducers is also provided, whereby the overall package size is reduced by electrically connecting signal wires to array electrodes at an angle approximately normal to the array surface, thus largely eliminating the bend radius requirements of conventional printed circuit boards or flex circuits.



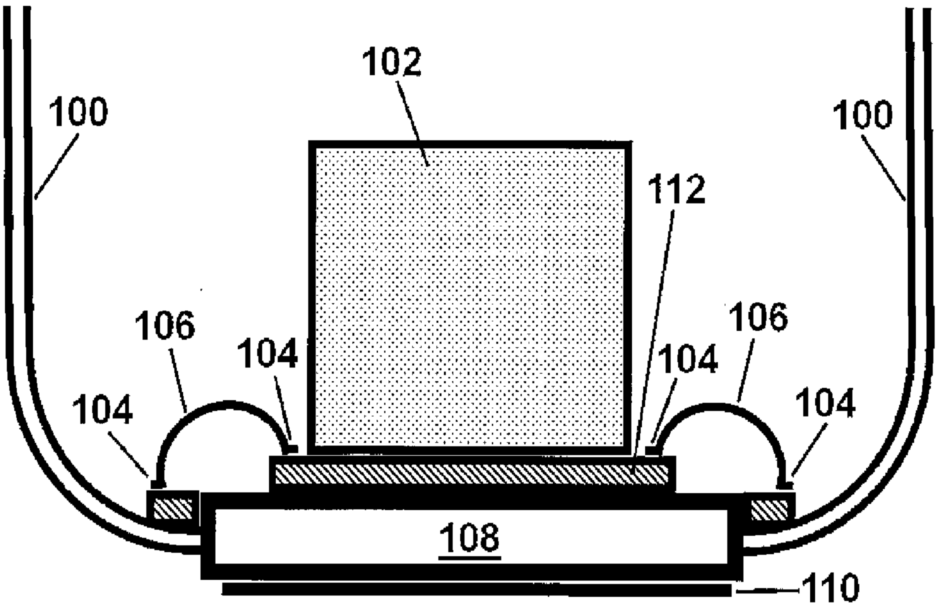


FIG. 1

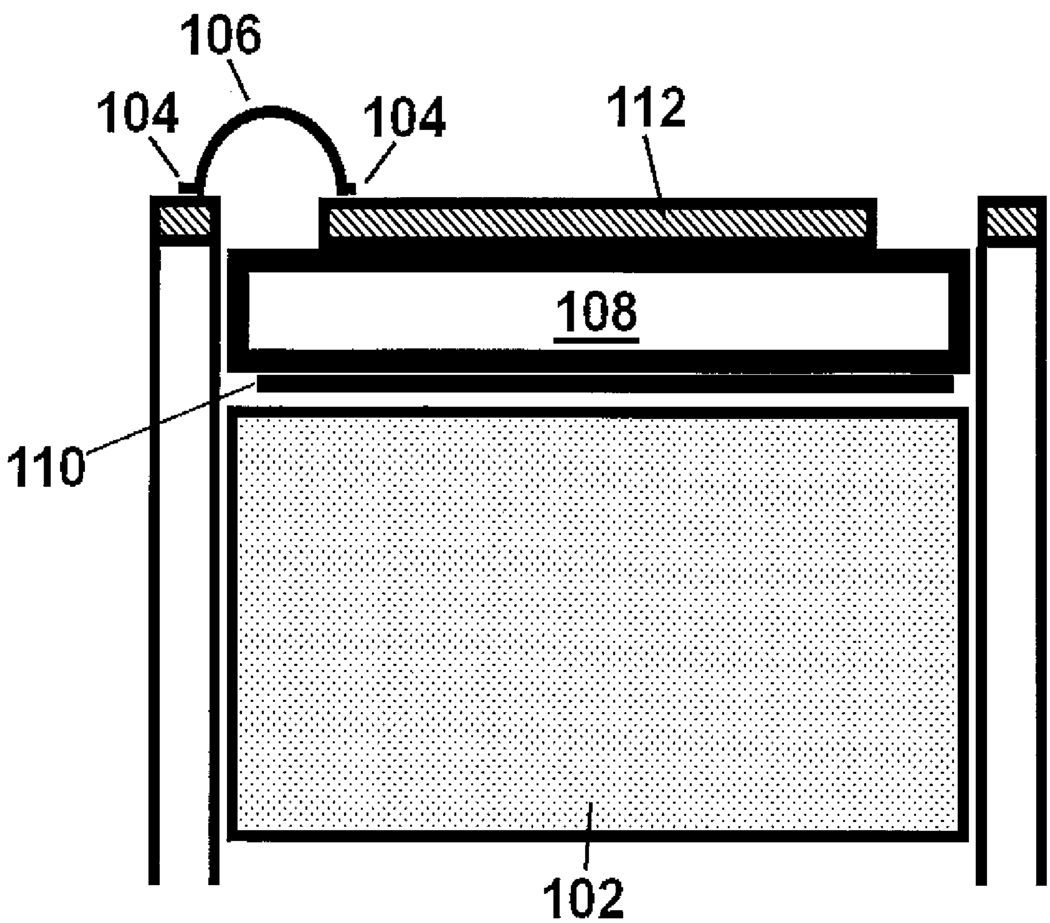


FIG. 2

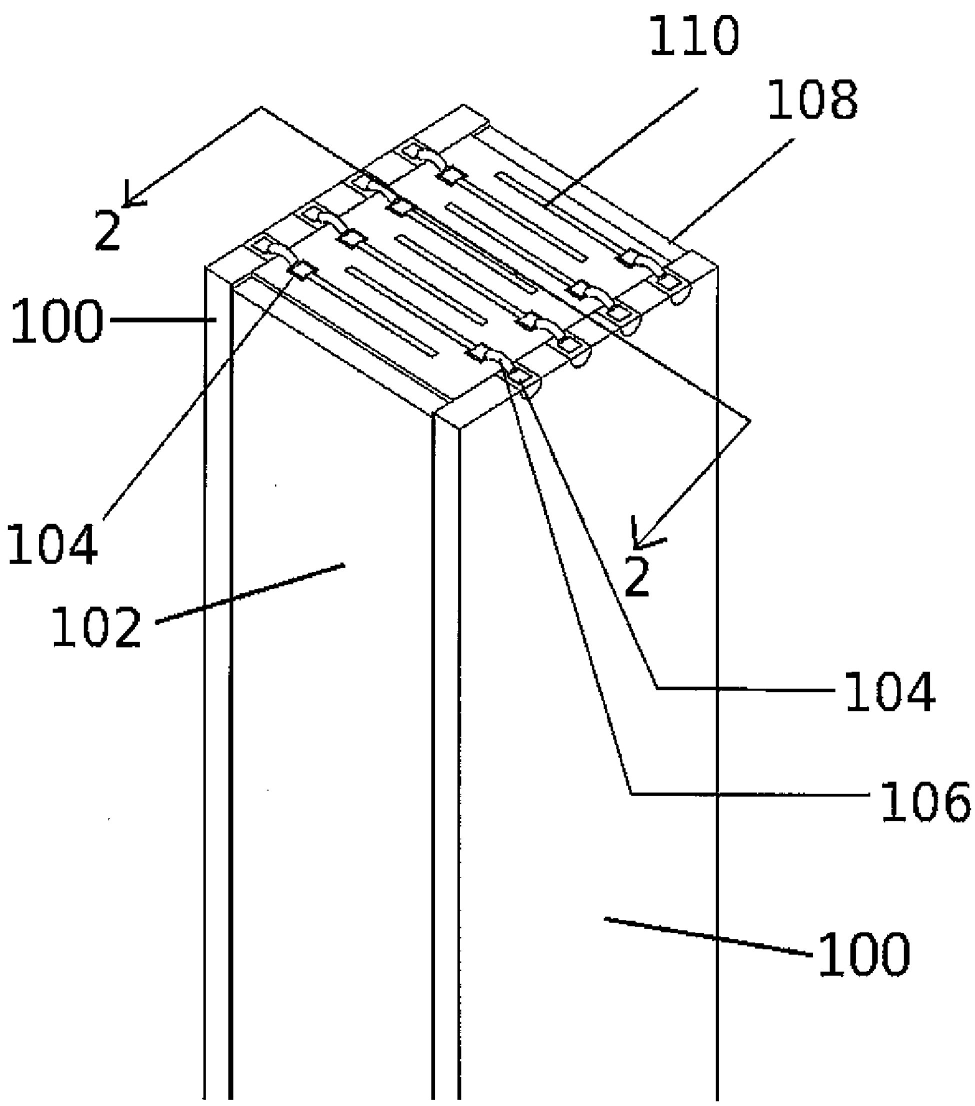


FIG. 3

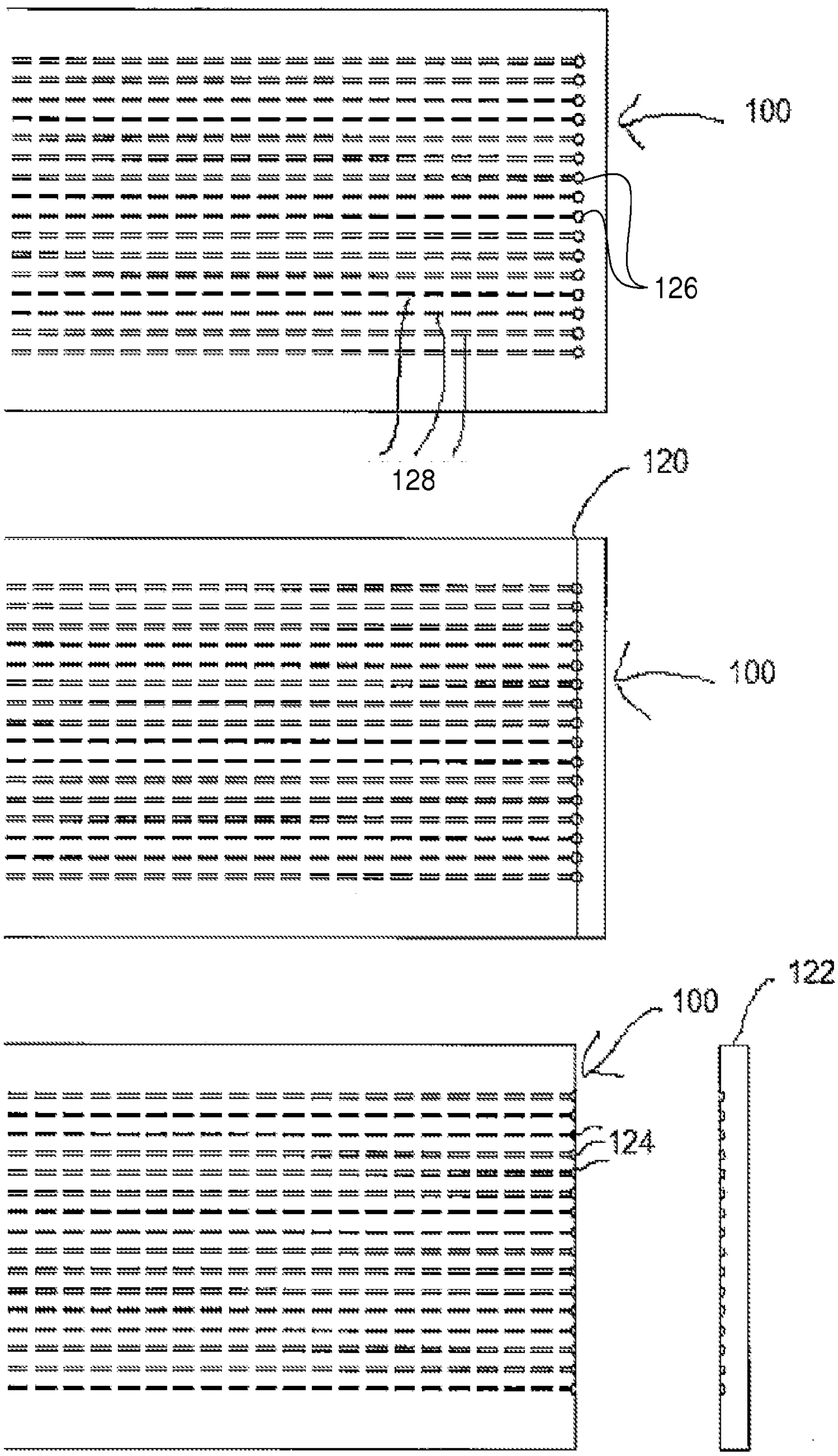


FIG. 4

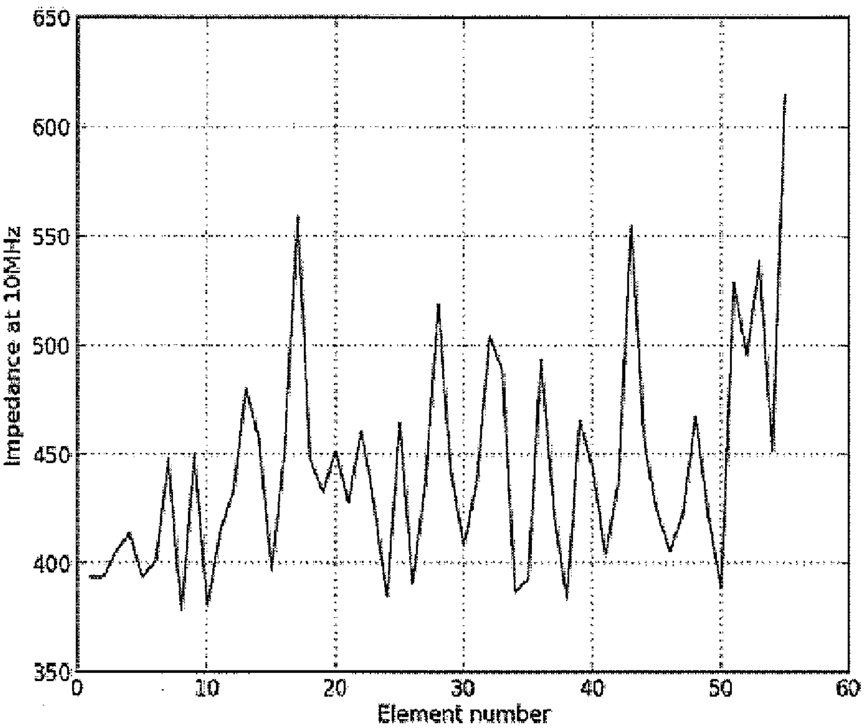

650
600
550
500
450
400
350
Impedance at 10MHz
0
10
20
30
40
50
60
Element number

FIG. 5

ULTRASOUND ENDOSCOPE AND METHODS OF MANUFACTURE THEREOF

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application Ser. No. 61/681,320, filed Aug. 9, 2012, and of U.S. Provisional Patent Application Ser. No. 61/710,696, filed Oct. 6, 2012; each of which is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] Array-based endoscopic ultrasound systems operating at frequencies in the 1-10 MHz range are used frequently for laparoscopic imaging where they provide fast scanning rates, dynamic focusing and beam steering. For endoscopic imaging applications requiring higher resolution such as intravascular, intracardiac, transurethral, trans-nasal and transtympanic imaging, ultrasound arrays have been challenging to manufacture owing the small element size, small element pitch and need to package the finished endoscope into a small enough package to enter the required lumens. These applications have, therefore, been served mainly by single element ultrasound endoscopes which, compared to arrays, suffer slower frame rates, a tradeoff between depth of field and lateral resolution and the necessity of having moving parts in the endoscope head which adds bulk and causes unwanted vibrations.

[0003] In recent years there has been significant progress in developing fully sampled forward looking high frequency linear array transducers. For most applications a phase-array endoscope would offer significant improvements over a single-element endoscope. However, although the elements are conventionally proportioned in these arrays, the overall packaging of the transducers remains relatively large. This limits the application of the arrays to topical use where images are generated from outside the body.

SUMMARY

[0004] In general, in an aspect, an ultrasonic array has piezoelectric material and a plurality of electrodes. Each electrode is electrically connected to a respective signal wire, and the plurality of signal wires are embedded in a printed circuit board, the board having an angle of greater than about **60** degrees with respect to the array. In certain implementations, the configuration described above is included in an endoscope. The angle can be greater than **70** degrees. The angle can be greater than 80 degrees. The angle can be approximately 90 degrees. The printed circuit board can be a flexible circuit.

[0005] In general, in an aspect, a method of manufacture of any of the above includes creating vias in the printed circuit board and cutting the vias transversely to expose conductive material at the edge of the board. In certain implementations, the array is then wire bonded to the conductive material, such that the material acts as a wire bonding pad. Other implementations are possible, such as generally when the array is electrically connected to the conductive material by thin metal film, conductive epoxy, or the like. The cutting can be accomplished by a dicing saw or by similar methods. The cutting can be accomplished by a laser.

[0006] In general, in an aspect, an ultrasonic array has piezoelectric material and a plurality of electrodes. Each electrode is correspondingly electrically connected to one of a plurality of signal wires, the wires having an angle of greater than about 60 degrees with respect to the array. In certain implementations, the angle can be greater than 70 degrees. The angle can be greater than 80 degrees. The angle can be approximately 90 degrees.

[0007] In general, in an aspect, a method of manufacture of approximately perpendicular wire bonds includes creating vias in a flexible circuit and cutting the vias transversely to expose conductive material at the edge of the flexible circuit.

[0008] In general, in an aspect, a method of manufacture of electrical connections between an ultrasonic array and a printed circuit board includes creating vias in the board and cutting the vias transversely to expose the conductive material at the edge of the board.

[0009] These and other features and aspects, and combinations of them, may be expressed as methods, systems, components, means and steps for performing functions, business methods, program products, and in other ways.

[0010] Other advantages and features will become apparent from the following description and from the claims.

DESCRIPTION

[0011] FIG. **1** shows a partial perspective view of the probe end of a conventional endoscope.

[0012] FIG. **2** shows a sectional view of the probe end of an endoscope of the present invention.

[0013] FIG. **3** shows a partial perspective view of the probe end of an endoscope of the present invention.

[0014] FIG. **4** depicts steps, from top to bottom, in the method of manufacture of the present invention.

[0015] FIG. **5** shows a graph of impedance in ohms at 10 MHz vs array element number for the endoscope of the Example.

PARTS LEGEND

[0016] **100** Flex circuit, printed circuit board

[0017] **102** Transducer stack, backing

[0018] **104** Wire bonding pads

[0019] **106** Wire to/from array element

[0020] **108** Piezoelectric material

[0021] **110** Electrodes

[0022] **112** Array, ultrasonic array

[0023] **120** Cut

[0024] **122** Discarded half of the board edge

[0025] **124** Exposed conductive material at the board edge

[0026] **126** Via

[0027] **128** Signal wire

[0028] Miniaturized high-frequency, ultrasonic phased array endoscopes have been successfully designed and fabricated. An array with an electrical harness (such as flex or PCB or series of conductors) may be set a defined angle relative to a stack. There may be no bend required. The volumetric footprint can be minimized as well as the number of components.

[0029] The advantages of an endoscope of this invention, as well as methods of manufacture of such endoscopes, can be seen by contrast to a conventional endoscope design in FIG. **1**. At the probe end, a surface of piezoelectric material **108** is systematically electroded with electrodes **110**, such that it defines an array **112** of individual elements that transmit and receive acoustic signals. Piezoelectric materials such as lead zirconate titanate (PZT) or lead manganese niobate in solid solution with lead titanate (PMNx-PT(1-x)) are often used. To achieve additional separation between elements, in some cases kerfs (cuts made into the piezoelectric material **108**) are made using a saw, laser, reactive ion etching or other methods. Each element in the array **112** is electrically connected (generally by way of a wire bonding pad) to a wire **106**, which is correspondingly electrically connected on its other end by wire bonding pads **104** on a printed circuit board **100**. Signal wires (not shown) embedded in the printed circuit board **100** are electrically connected to each pad **104**, and send each signal from each element to the distal end of the probe (this is the end which is mechanically manipulated by a clinician). Often, the printed circuit board is a flexible (flex) circuit, which packages many of signal wires composed of conductive material by sandwiching them between flexible polymer layers. Printed circuit board **100** could also be inflexible, in which the insulating layers may be FR-**4** fiberglass.

[0030] Note that in the conventional endoscope design of FIG. **1**, a flex circuit **100** is approximately parallel to the surface of the array **112** for a significant distance before bending away from the probe end. The smallest dimension possible for such an endoscope is limited by how much of the flex circuit remains at the probe end. Typically, bonding pads **104** are exposed on both the flex circuit **100** and the array **112**, and wires **106** are used to attach array pads and flex circuit pads to each other. In order to prevent damage to the flex circuit **100**, the manufacturer specifies a minimum bend radius, often on the order of a few millimeters for a multilayer flex circuit such as those used to carry ultrasound array signals. This minimum bend radius requires that the flex circuit extend laterally from the ultrasound array for several millimeters before bending back, which greatly increases the cross-sectional area of the device. It is possible, in some embodiments, that no other structures are needed for mechanical support. In some embodiments, attachment may also be made to wires carried in another structure; if such structure is attached so that the wires meet the plane of the array surface, then a minimum bend radius may be required to avoid damaging such wires. Since the minimum size of a lumen into which the endoscope can enter is limited by the endoscope's cross-sectional area it is desirable to reduce the cross-sectional area as much as possible.

[0031] We now turn to an embodiment of the endoscope of the present invention; see FIGS. **2** and **3**. Rather than have a printed circuit board **100** (such as a flex circuit) wire bonded approximately parallel to the surface of an array **112**, instead the flex circuits are wire bonded (or otherwise electrically connected) approximately normal to the array surface. In such an arrangement the flex circuit does not bend, and the cross-sectional probe area need only be large enough to accommodate the array elements, bonding pads, and the thickness of the flex circuit at the probe end. This arrangement can be used in a variety of applications, including endoscopic high-frequency phased array ultrasound systems, non-endoscopic high-frequency ultrasound phased arrays, and both endoscopic and non-endoscopic phased and linear ultrasound arrays. In some embodiments, an endoscope of the present invention comprises a 40 MHz, 64-element phased array transducer packaged into a 2.47 mm by 2.42 mm endoscopic form factor, in which the array is a forward looking kerfless design based on PMN-32%PT with an element-to-element pitch of 38 microns. In some embodiments, the angle of the flex circuit with respect to the array is approximately 90 degrees. In some embodiments, the angle of the flex circuit with respect to the array is between 80 and 90 degrees. In some embodiments, the angle of the flex circuit with respect to the array is between 70 and 90 degrees. In some embodiments, the angle of the flex circuit with respect to the array is between about 60 and 90 degrees. In some embodiments crossing the normal plane, the angle of the flex circuit with respect to the array may exceed 90 degrees.

[0032] Attaching a printed circuit board approximately perpendicular to an array creates a manufacturing challenge because wire bonds between the array and the printed circuit board must connect to the board edge-on. In particular, flex circuitry is built by attaching together laminar layers, thus bonding pads cannot easily be mounted on the edge of a flex circuit. Moreover, because wire bonds are usually made between two parallel surfaces, it is difficult to make connections to bonding pads on the surface of a printed circuit board in this configuration, whether it is flexible or inflexible. The present invention solves these challenges by providing a novel method of manufacture. In some embodiments, this method enables wire bonding of signal wires to array elements; electrical connection is also possible using conductive epoxy or thin film metal deposition.

[0033] In a wire bonding embodiment, the method of manufacture includes the following steps (see FIG. **4**). A set of filled partial vias **126** is formed in the printed circuit board **100** (FIG. **4** top). These vias correspond to the position of the embedded signal wires **128**, which are composed of conductive material suitable for electrical connections. In some embodiments, this procedure is performed twice such that the vias **126** are arranged in two rows through the depth of the printed circuit board **100**, with one row through the top two layers and one through the bottom two layers such that they alternate. The board is then cut across its width with a dicing saw so as to cut the vias **126** in half near the edge of the board (FIG. **4** middle), exposing conductive material **124** corresponding to each signal wire at the site of the cut **120** (FIG. **4** bottom). The remainder **122** is discarded. In methods of manufacture of endoscopes of the present invention, wire bonds are then made between an array **112** and the cut vias **126** in the board, thus allowing a connection to be made without introducing any bending in the printed circuit board.

[0034] See below for an example of endoscopes of the present invention constructed using a method of manufacture of the present invention.

EXAMPLE

[0035] The array substrate was a 2.4 mm by 2.4 mm piece of PMN-32%PT lapped to 47 um thickness. An array of 64 electrodes was photolithographically defined on the top surface of this substrate with an electrode width of 27 um and an element-to-element pitch of 37 um. Each electrode was fanned out to a bonding pad arranged in two rows on each side of the array (four rows total). A 1.2 um layer of aluminum was sputtered onto the back side of the array to define a ground electrode, and a thick layer of conductive epoxy was attached to it to act as an absorbent acoustic backing layer. This epoxy was removed with a dicing saw in order to avoid making the bonding pads piezoelectrically active. Two 6-layer flex circuit boards were designed to connect to the elements from either side of the array. Each flex circuit had 32 traces terminating at individual copper-filled vias near the end of the board. The flex circuits were cut through the middle of the solid vias using a dicing saw. The two flex circuit boards were epoxied onto opposite sides of the transducer stack such that the diced vias were aligned with the bonding pads fanned out from the array. A jig was then machined to hold the flex+transducer stack upright in front of the wire-bonding tool. 15-micron thick aluminum wire bonds were used to connect the bonding pads on the array to the diced vias within the thickness of the array. The wirebonds were encapsulated with a thick insulating epoxy consisting of a 30% by volume mixture of Alumina powder and Epotek 301 (Epotek) insulating epoxy. A matching layer/lens combination was then epoxied onto the front face of the endoscope. Micro-coaxial cables were directly soldered to the flex circuit at the distal end of the probe.

[0036] Measurements of the impedance of the elements (see FIG. **5**) measured from the distal end of the flex circuit show that this technique does indeed provide a good electrical connection to the transducer elements, with low impedance electrical connections in the wire bond between the flex circuit and the array.

1-14. (canceled)

15. An ultrasound device comprising:

a transducer stack comprising:

an array of ultrasound elements in electrical communication with a respective set of ultrasound array bonding pads;

wherein the transducer stack comprises an ultrasound emitting surface and a plurality of side walls; and

a printed circuit board, wherein a distal portion of said printed circuit board is provided adjacent to a first side wall of said transducer stack, wherein an angle between the distal portion of the printed circuit board and the ultrasound emitting surface is at least 60 degrees, and wherein said printed circuit board comprises:

a substrate comprising a plurality of conductive paths extending longitudinally therethrough;

said substrate having a distal surface comprising a plurality of lateral bonding pads in electrical communication with respective electrically conductive paths within said substrate;

wherein said distal surface of said printed circuit board is positioned proximate to said ultrasound emitting surface; and

wherein electrical connections are provided between said lateral bonding pads of said printed circuit board and said ultrasound array bonding pads.

16. The ultrasound device according to claim **15** wherein the distal portion of said printed circuit board is parallel to the first side wall of said transducer stack.

17. The ultrasound device according to claim **15** wherein the printed circuit board comprises:

a linear array of vias formed within said substrate at a distal end of said substrate, such that the vias intersect respective electrically conductive paths within said substrate;

wherein said vias are filled with an electrically conductive material; and

wherein said vias are exposed in said distal surface of said substrate, forming said plurality of lateral bonding pads in said distal surface.

18. The ultrasound device according to claim **17** wherein said printed circuit board is positioned relative to said transducer stack such that said lateral bonding pads are coplanar with said ultrasound array bonding pads.

19. The ultrasound device according to claim **17** wherein said printed circuit board is positioned relative to said transducer stack such that said lateral bonding pads are coplanar with said ultrasound emitting surface.

20. The ultrasound device according to claim **17** wherein the printed circuit board is adhered to the first side wall of the transducer stack.

21. The ultrasound device according to claim **17** wherein the printed circuit board is flexible.

22. The ultrasound device according to claim **17** wherein the printed circuit board is a first printed circuit board and the plurality of lateral bonding pads are a first plurality of lateral bonding pads, the ultrasound device further comprising a second printed circuit board comprising a second plurality of lateral bonding pads;

wherein a distal portion of said second printed circuit board is provided adjacent to a second side wall of said transducer stack, wherein an angle between the distal portion of the second printed circuit board and the ultrasound emitting surface is at least 60 degrees;

wherein a distal surface of said second printed circuit board is positioned proximate to said ultrasound emitting surface; and

wherein electrical connections are provided between said second plurality of lateral bonding pads of said second printed circuit board and said ultrasound array bonding pads.

23. The ultrasound device according to claim **22** wherein said first printed circuit board and said second printed circuit board are provided on opposite sides of said transducer stack.

24. The ultrasound device according to claim **23** wherein said ultrasound array bonding pads comprise a first array of ultrasound bonding pads and a second array of ultrasound bonding pads;

wherein said first array of ultrasound bonding pads is provided proximate to said first side wall and said second plurality of lateral bonding pads is provided proximate to said second side wall;

wherein electrical connections between said first array of ultrasound bonding pads and said ultrasound array elements, and between said second plurality of lateral bonding pads and said ultrasound array elements, are spatially interleaved; and

wherein said first plurality of lateral bonding pads are electrically connected to said first array of ultrasound bonding pads, and said second plurality of lateral bonding pads are connected to said second array of ultrasound bonding pads.

25. An ultrasound probe comprising an ultrasonic device according to claim **15**.

26. A method of electrically connecting an array of ultrasound elements to a printed circuit board, wherein the ultrasound elements are in electrical communication with a respective set of ultrasound array bonding pads, the method comprising:

forming a linear array of vias within the printed circuit board, such that the vias intersect respective electrically conductive paths that extend longitudinally through the printed circuit board;

filling the vias with an electrically conductive material, thereby forming a linear array of filled vias within the printed circuit board;

cutting the printed circuit board transversely through the linear array of filled vias to form a distal surface of the printed circuit board, such that the linear array of filled vias are cut to form a plurality of lateral bonding pads and to expose the plurality of lateral bonding pads at the distal surface, wherein the lateral bonding pads are in electrical communication with respective electrically conductive paths within the printed circuit board; and

forming electrical connections between the lateral bonding pads and the ultrasound array bonding pads.

27. The method according to claim **26** wherein the electrical connections are formed by wire bonding.

28. The method according to claim **26** wherein the electrical connections are formed by thin metal film or conductive epoxy.

29. The method according to claim **26** wherein the printed circuit board is flexible.

30. The method according to claim **26** wherein the vias are partial vias.

31. The method according to claim **30** wherein the vias are arranged in two rows through the depth of the printed circuit board, wherein one row of vias extends through the a plurality of top layers of the printed circuit board, and the other row of vias extends through the a plurality of bottom layers of the printed circuit board, and wherein the vias in the two rows are spatially interleaved across the printed circuit board.

32. A printed circuit board comprising:

a substrate comprising a set of electrically conductive paths;

a linear array of vias formed within said substrate at an edge of said substrate, the vias intersecting respective electrically conductive paths within said substrate;

wherein said vias are filled with an electrically conductive material; and

wherein a lateral surface of said substrate is defined at a location that intersects the linear array of vias, such that a plurality of electrical contacts are formed in said lateral surface.

33. The circuit board according to claim **32** wherein the vias are partial vias.

34. The circuit board according to claim **32** wherein the printed circuit board is flexible.

35. A method of forming a plurality of lateral bonding pads on a distal surface of a printed circuit board, the method comprising:

forming a linear array of vias within the printed circuit board, the vias intersecting respective electrically conductive paths that extend longitudinally through the printed circuit board;

filling the vias with an electrically conductive material, thereby forming a linear array of filled vias within the printed circuit board; and

cutting the printed circuit board transversely through the linear array of filled vias to form the distal surface of the printed circuit board, such that the linear array of filled vias are cut to form the plurality of lateral bonding pads and to expose the plurality of lateral bonding pads at the distal surface, wherein the lateral bonding pads are in electrical communication with respective electrically conductive paths within the printed circuit board.

36. The circuit board according to claim **35** wherein the printed circuit board is flexible.

37. The circuit board according to claim **35** wherein the vias are partial vias.

* * * * *

专利名称(译)	超声内窥镜及其制造方法		
公开(公告)号	US20150209005A1	公开(公告)日	2015-07-30
申请号	US14/420452	申请日	2013-08-09
申请(专利权)人(译)	达尔豪斯大学		
当前申请(专利权)人(译)	达尔豪斯大学		
[标]发明人	BEZANSON ANDRE B ADAMSON ROBERT B A BROWN JEREMY A		
发明人	BEZANSON, ANDRE B. ADAMSON, ROBERT B. A. BROWN, JEREMY A.		
IPC分类号	A61B8/12 A61B8/00 H05K1/02 H05K3/30 H05K1/11 G01N29/24 H05K3/42		
CPC分类号	A61B8/12 G01N29/2437 A61B8/4488 G01N2291/028 H05K3/30 H05K1/115 H05K1/028 H05K3/429 H05K1/189 H05K3/0052 H05K3/403 H05K2203/049 Y10T29/49151 Y10T29/49165		
优先权	61/710696 2012-10-06 US 61/681320 2012-08-09 US		
其他公开文献	US10149660		
外部链接	Espacenet USPTO		

摘要(译)

为了解决传统换能器的限制，相控阵换能器具有适合于包装到例如内窥镜中的形状因子。还提供了一种制造小型封装换能器的方法，通过以大致垂直于阵列表面的角度将信号线电连接到阵列电极来减小整个封装尺寸，从而大大消除了传统印刷电路板的弯曲半径要求或柔性电路。