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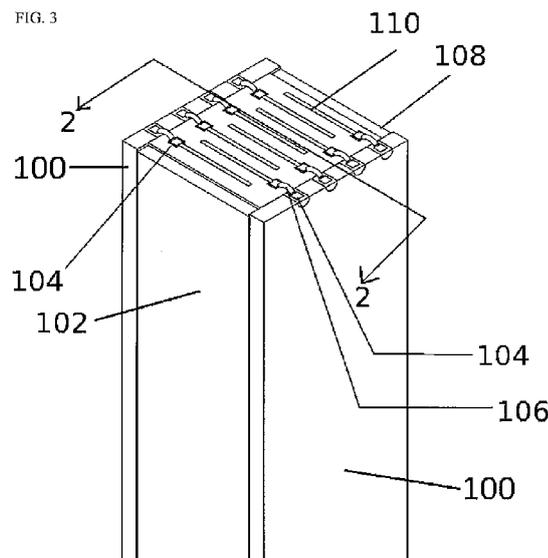
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(54) Title: ULTRASOUND ENDOSCOPE AND METHODS OF MANUFACTURE THEREOF

FIG. 3



(57) Abstract: To address limitations of conventional transducers, a phased array transducer is provided with a form factor suitable 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.

WO 2014/022938 A1

ULTRASOUND ENDOSCOPE AND METHODS OF MANUFACTURE THEREOF

CROSS-REFERENCE TO RELATED APPLICATIONS

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

Array-based endoscopic ultrasound systems operating at frequencies in the 1-10MHz 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.

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

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.

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.

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.

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.

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.

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.

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

DESCRIPTION

FIG. 1 shows a partial perspective view of the probe end of a conventional endoscope.

FIG. 2 shows a sectional view of the probe end of an endoscope of the present invention.

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

FIG. 4 depicts steps, from top to bottom, in the method of manufacture of the present

invention.

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

Parts Legend

- 100 Flex circuit, printed circuit board
- 102 Transducer stack, backing
- 104 Wire bonding pads
- 106 Wire to/from array element
- 108 Piezoelectric material
- 110 Electrodes
- 112 Array, ultrasonic array
- 120 Cut
- 122 Discarded half of the board edge
- 124 Exposed conductive material at the board edge
- 126 Via
- 128 Signal wire

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.

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.

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.

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.

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.

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.

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

Example

The array substrate was a 2.4mm 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.

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.

CLAIMS:

1. An ultrasonic array comprising piezoelectric material and a plurality of electrodes, in which each electrode is correspondingly electrically connected to one of a plurality of signal wires embedded in a printed circuit board, the board having an angle of greater than about 60 degrees with respect to the array.
2. An endoscope comprising the apparatus of claim 1.
3. An ultrasonic array comprising piezoelectric material and a plurality of electrodes, in which 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.
4. The apparatus of any of claims 1-3, in which the angle is greater than 70 degrees.
5. The apparatus of any of claims 1-3, in which the angle is greater than 80 degrees.
6. The apparatus of any of claims 1-3, in which the angle is approximately 90 degrees.
7. The apparatus of any of claims 1-2, in which the printed circuit board is flexible.
8. A method of manufacture of the apparatus of any of claims 1, 2, or 4-7 comprising creating vias in the printed circuit board and cutting the vias transversely to expose conductive material at the edge of the board.
9. The method of claim 8, in which the array is then wire bonded to the conductive material, whereby the material acts as a wire bonding pad.
10. The method of claim 8, in which the array is then electrically connected to the conductive material.
11. The method of any of claims 8-10, in which the cutting is effected by a dicing saw.
12. The method of any of claims 8-10, in which the cutting is effected by a laser.
13. A method of manufacture of approximately perpendicular wire bonds comprising creating vias in a flexible circuit having embedded conductive material and cutting the vias transversely to expose the conductive material at the edge of the flexible circuit.
14. A method of manufacture of electrical connections between an ultrasonic array and a printed circuit board having embedded conductive material comprising creating vias in the board and cutting the vias transversely to expose the conductive material at the edge of the board.

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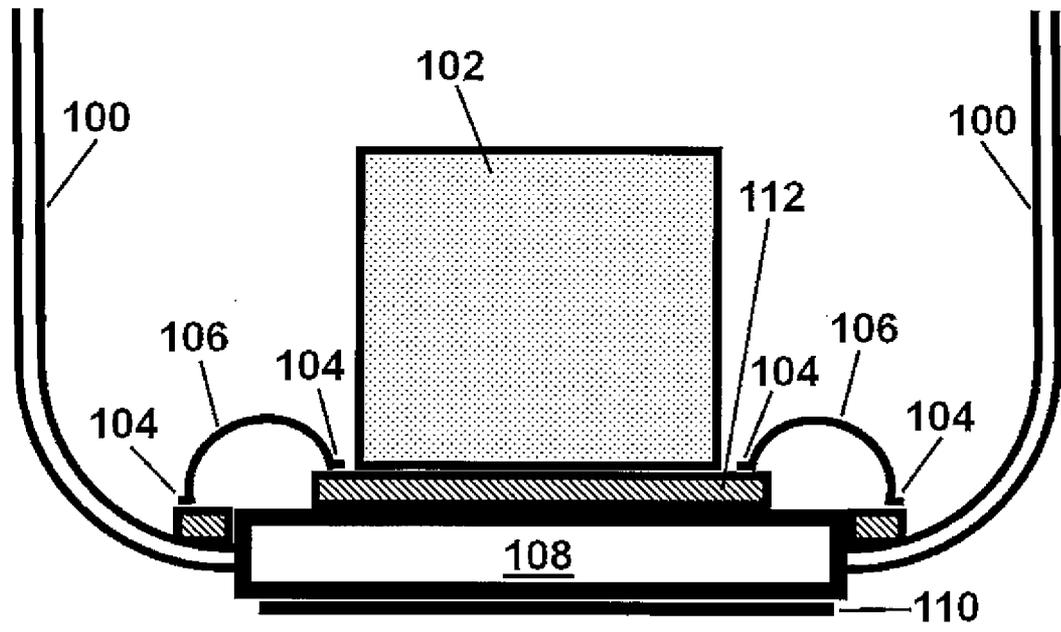


FIG. 1

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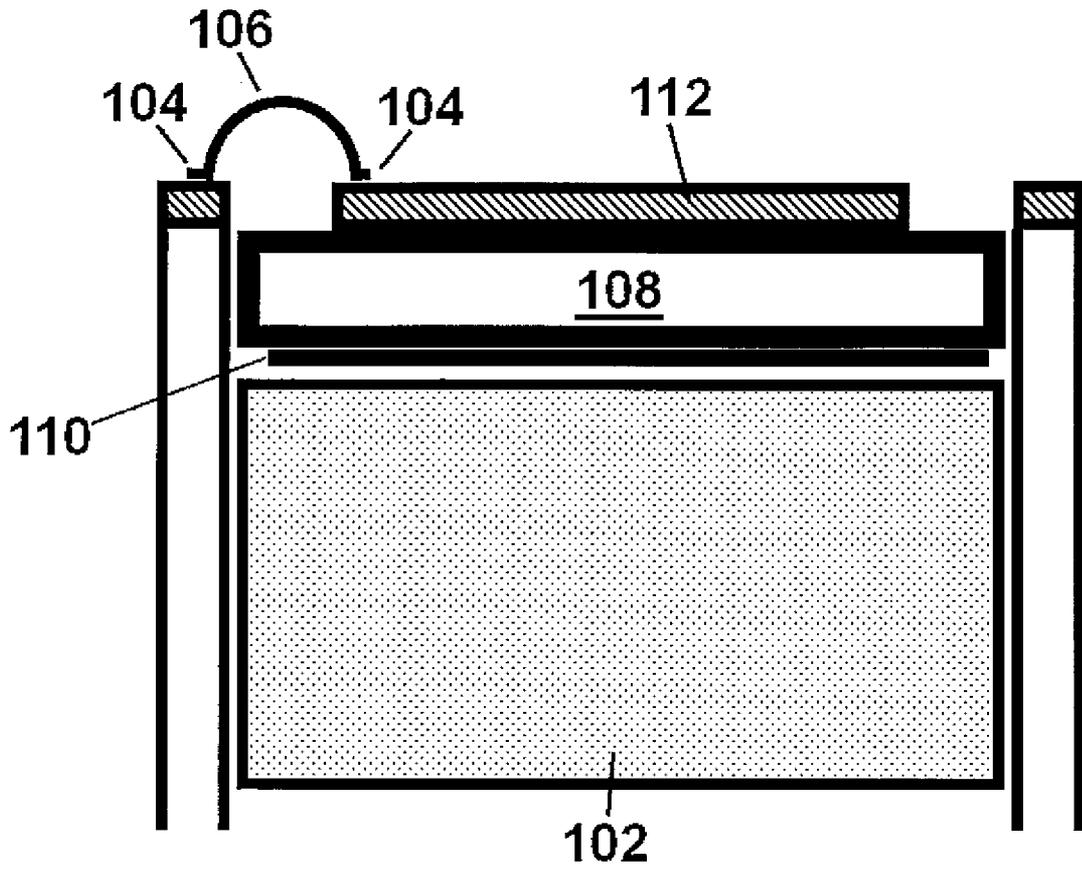


FIG. 2

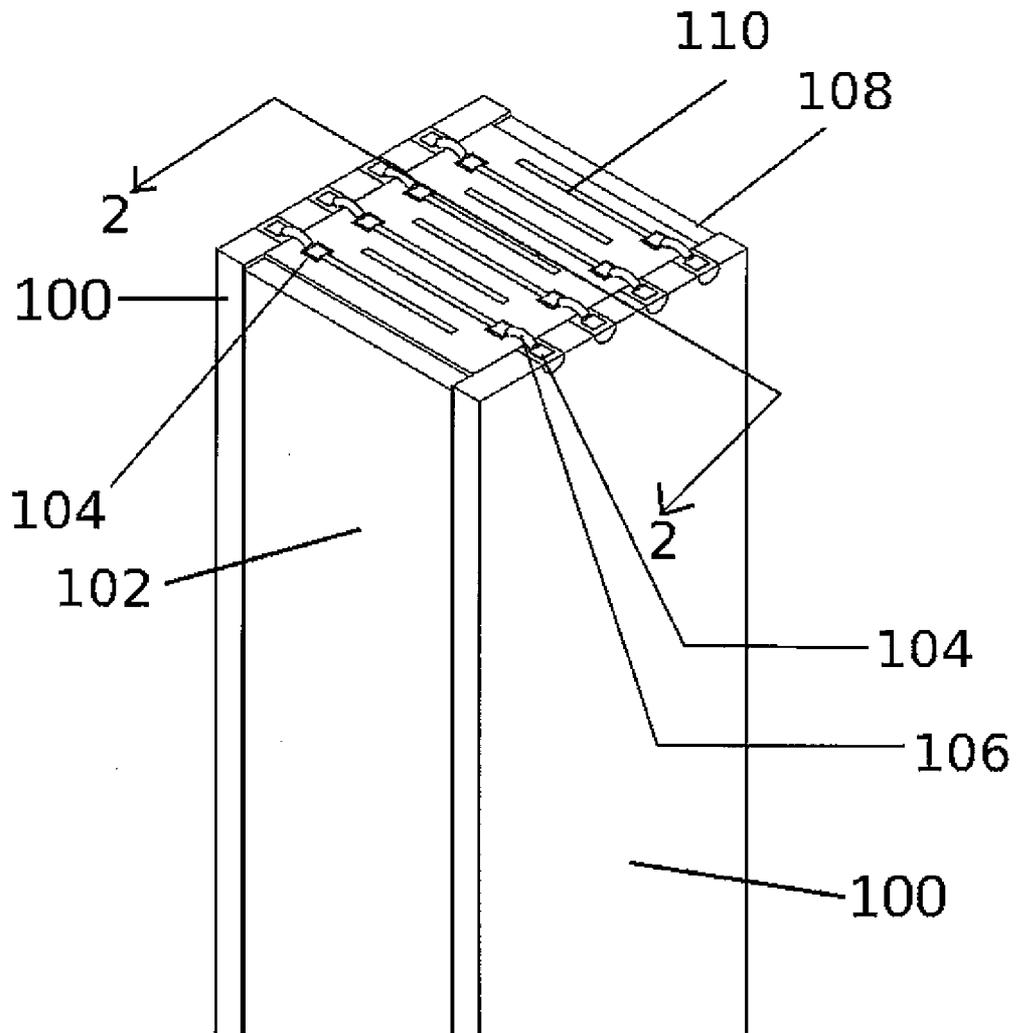


FIG. 3

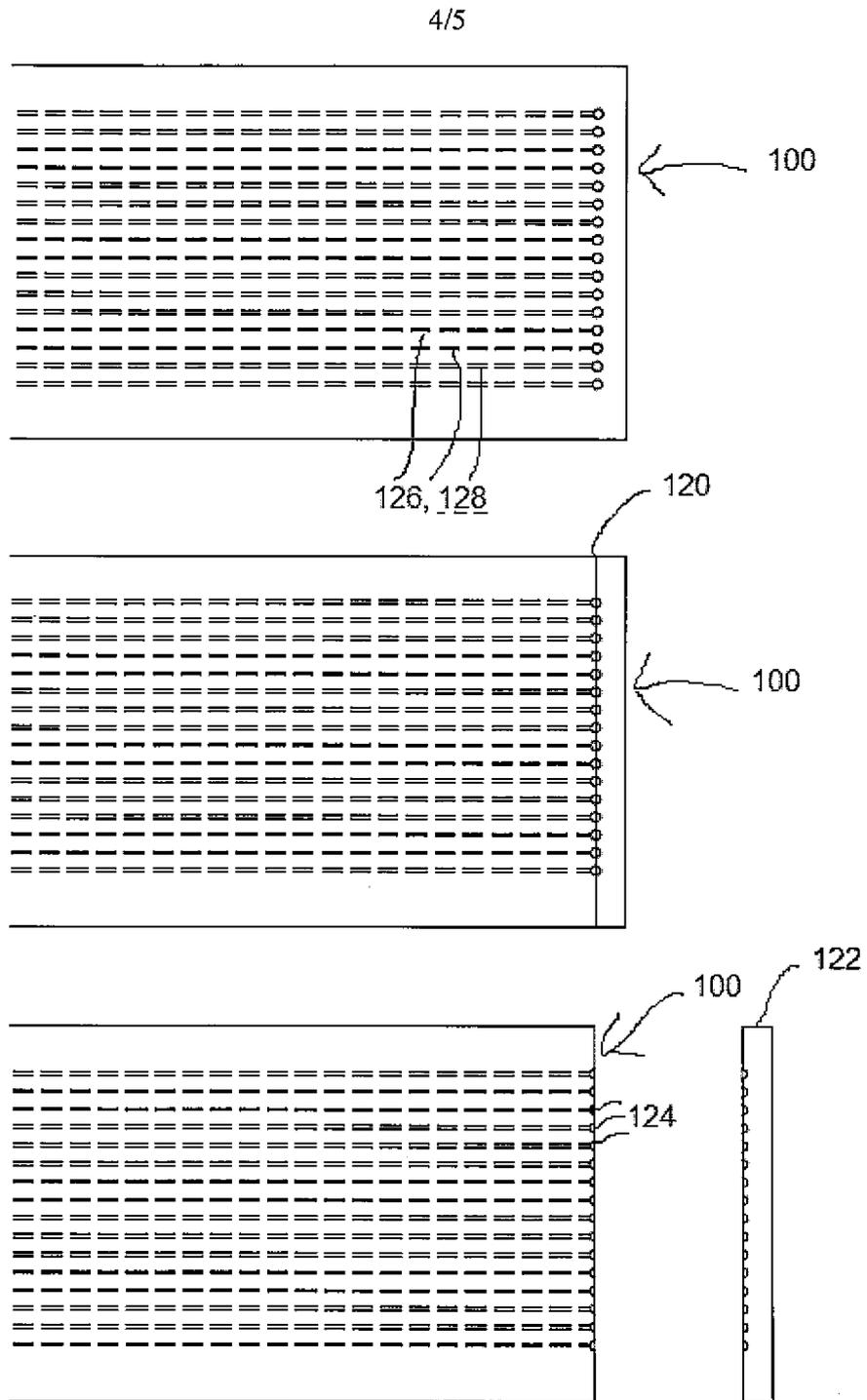


FIG. 4

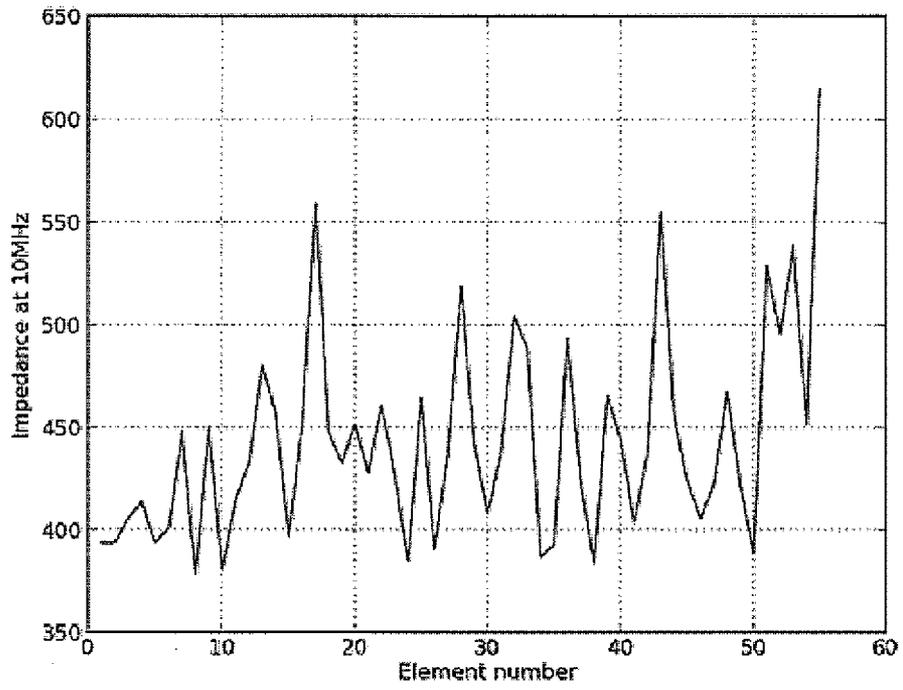


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2013/050613

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **H05K 3/32** (2006.01) , **A61B 8/12** (2006.01) , **G01S 15/89** (2006.01) , **G01S 7/52** (2006.01) ,
H05K 3/42 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: H05K 3/32

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

IPC: H05K *

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
TotalPatent, Espacenet, Canadian Patents Database; keywords: "flexible circuit", "printed circuit board", travers*, connect*, edge, piezoelectric, electrode*, wire, "ultrasonic array", PCB, flex, perpendicular, bend, bent, cut*, expos*, conductive

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2007/0222339 A1 (Lukacs et al.) 27 September 2007 (27-09-2007) figs. 1, 11, 29 and 44	1, 2, 7, 14
Y	US 6 541 896 B1 (Piel Jr. et al.) figs. 6A and 6B, Abstract	1, 2, 7
Y	US 20090221873 A1 (McGrath) fig. 6 and par. 42, lines 1-2	2
Y	US 8 189 342 B2 (Band et al.) figs. 12 and 13 and col. 5, lines 6-36	14

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

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

Date of the actual completion of the international search

25 September 2013 (25-09-2013)

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2013/050613

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US2007222339A1	27 September 2007 (27-09-2007)	CA2563775A1 CN1998095A CN1998095B EP1738407A2 EP1738407A4 JP2007534277A JP4805254B2 US2005272183A1 US7230368B2 US2007182287A1 US7830069B2 WO2005104210A2 WO2005104210A3	03 November 2005 (03-11-2005) 11 July 2007 (11-07-2007) 03 November 2010 (03-11-2010) 03 January 2007 (03-01-2007) 04 June 2008 (04-06-2008) 22 November 2007 (22-11-2007) 02 November 2011 (02-11-2011) 08 December 2005 (08-12-2005) 12 June 2007 (12-06-2007) 09 August 2007 (09-08-2007) 09 November 2010 (09-11-2010) 03 November 2005 (03-11-2005) 14 December 2006 (14-12-2006)
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