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(54) **METHOD FOR FORMING AN ULTRASOUND DEVICE, AND ASSOCIATED APPARATUS**

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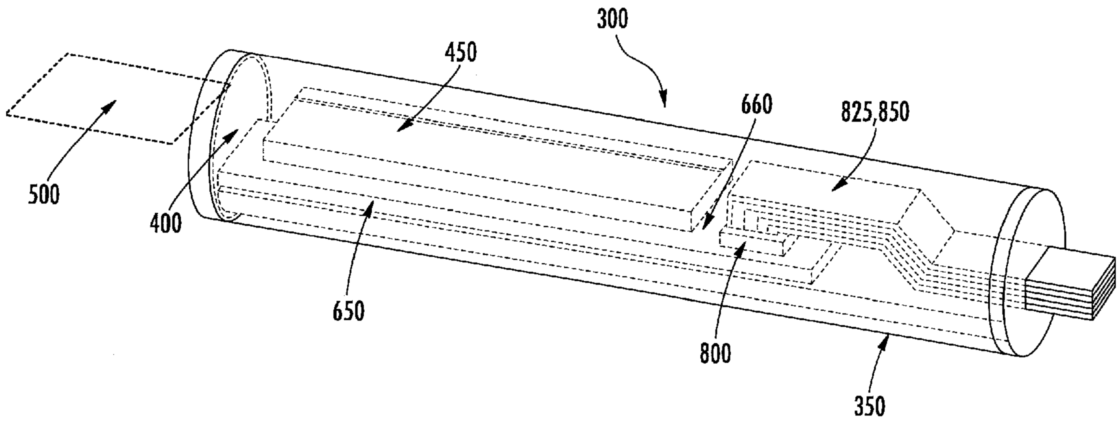
USPC **600/466**; 600/459; 29/25.35

(57) **ABSTRACT**

A method and apparatus directed to formation of a connection with an ultrasonic transducer apparatus (UTA) comprising a transducer device having first and second electrodes is provided. The UTA is engaged with an interposer device surface. The interposer device is greater in at least one lateral dimension than and extends laterally outward of the UTA, and comprises at least two laterally-extending conductors. A conductive engagement is formed between the first and second electrodes and respective first ends of the conductors. A connection support substrate is engaged with the interposer device about second ends of the conductors, and includes at least two connective elements for forming a conductive engagement with the respective second ends of the conductors. The UTA is then inserted into a catheter member lumen such that the device plane of the UTA and the at least two connective elements extend axially along the lumen.



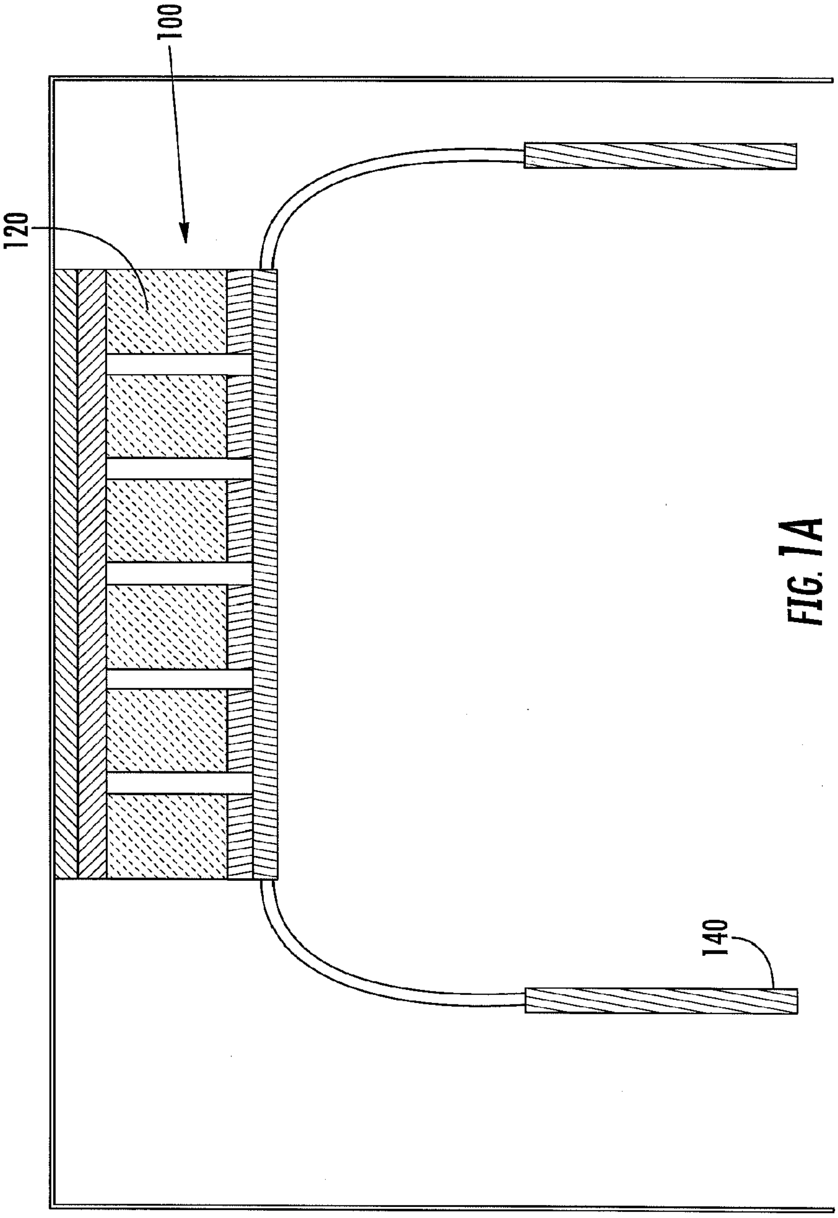


FIG. 1A
PRIOR ART

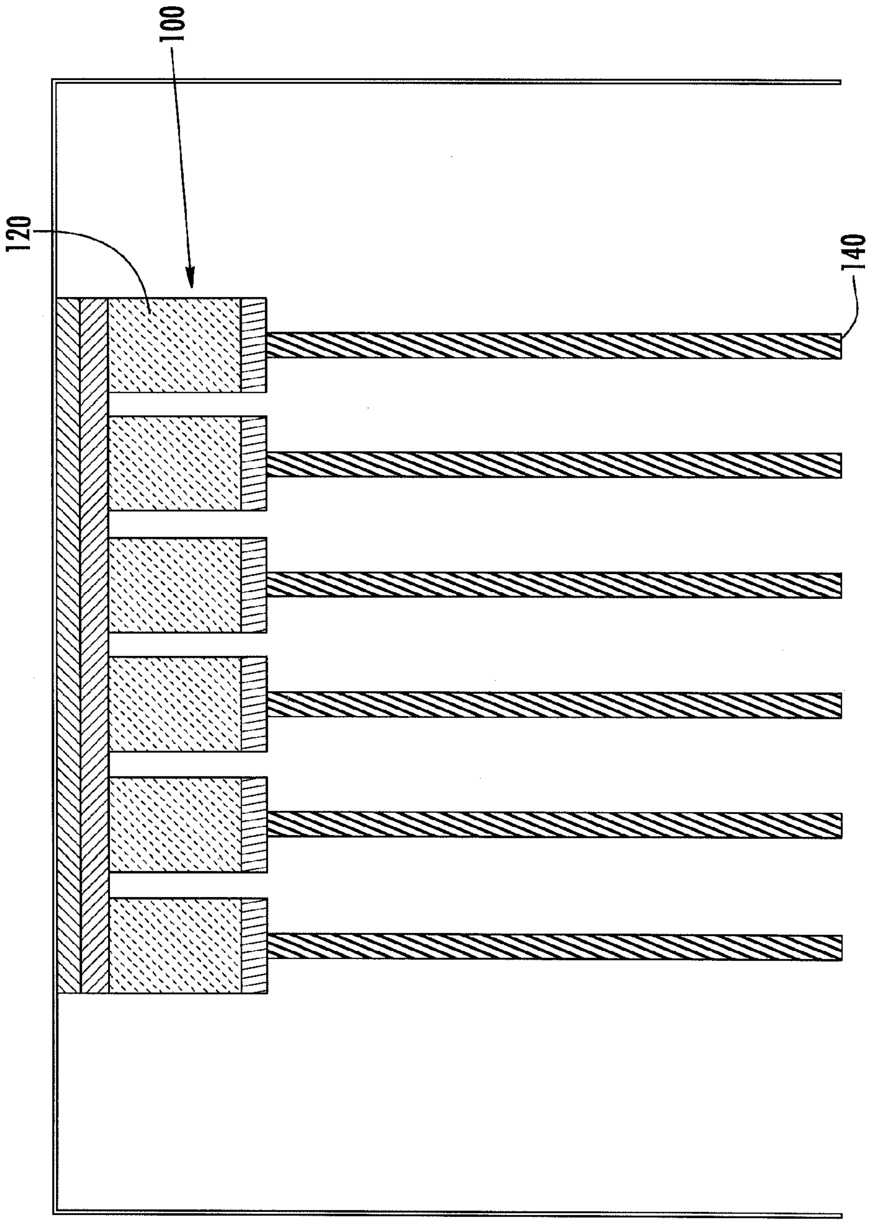


FIG. 1B
PRIOR ART

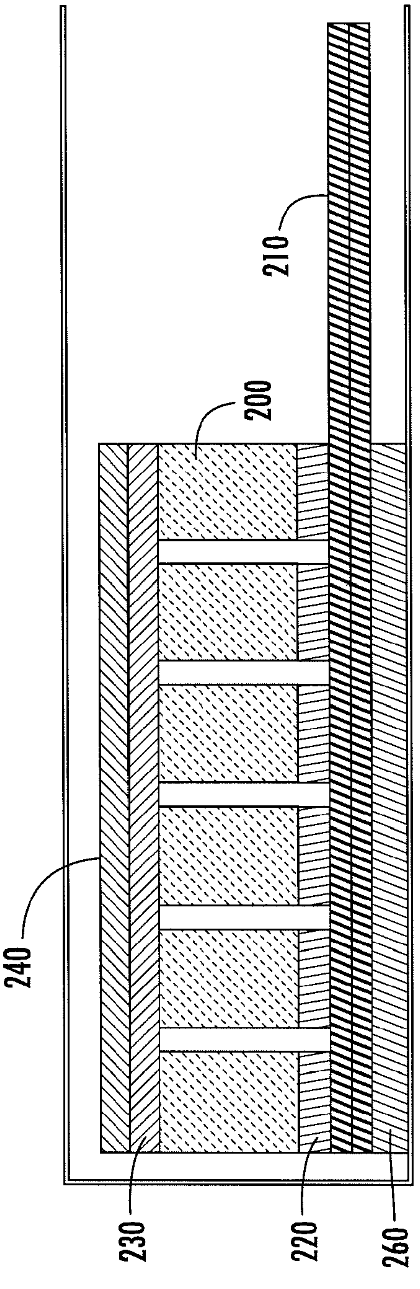


FIG. 2
PRIOR ART

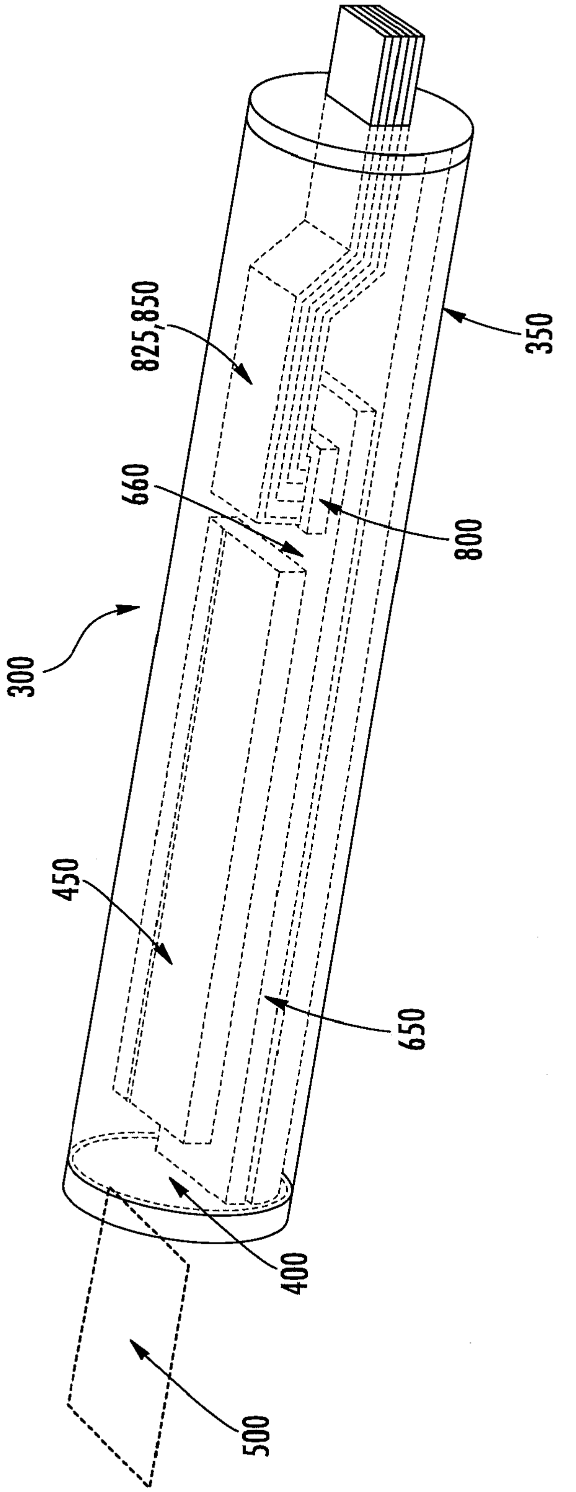


FIG. 3

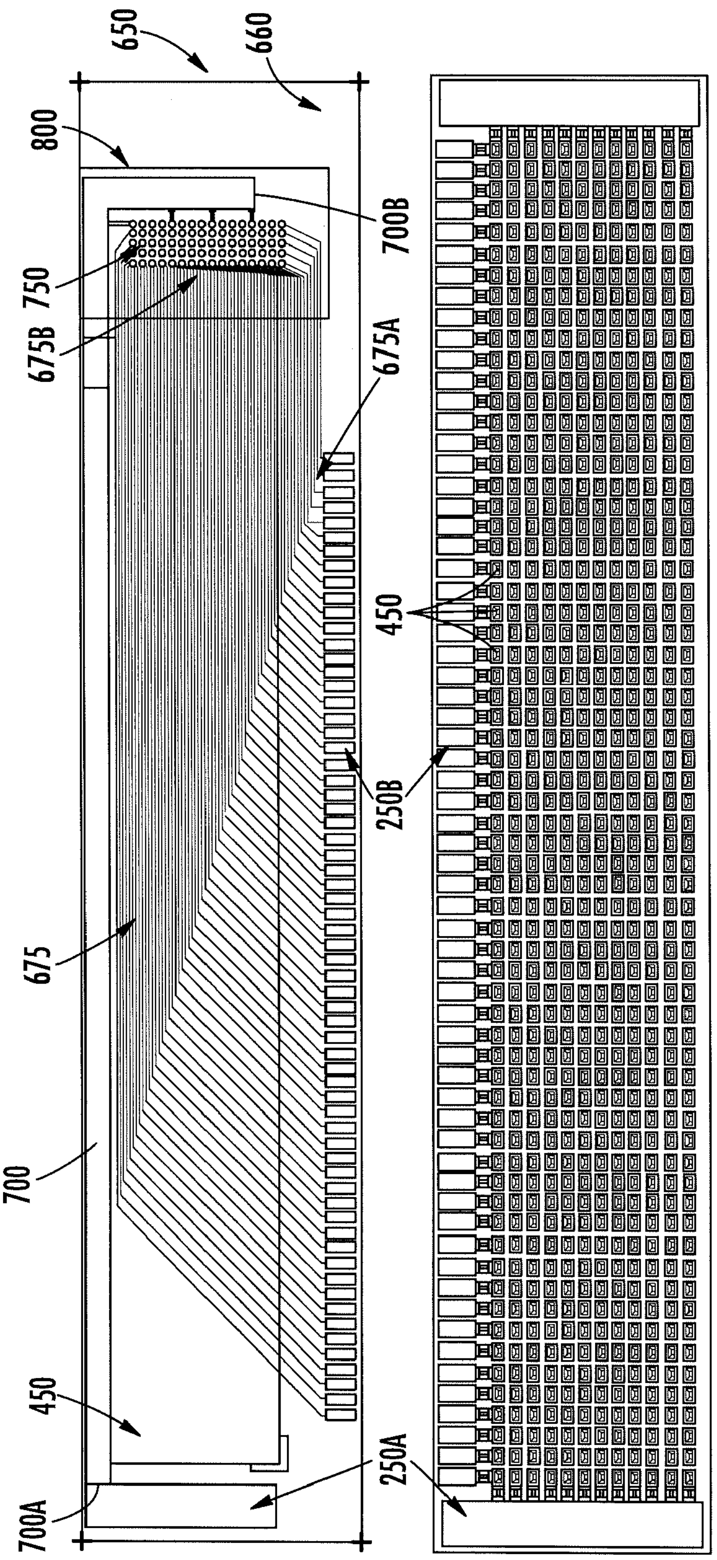


FIG. 4

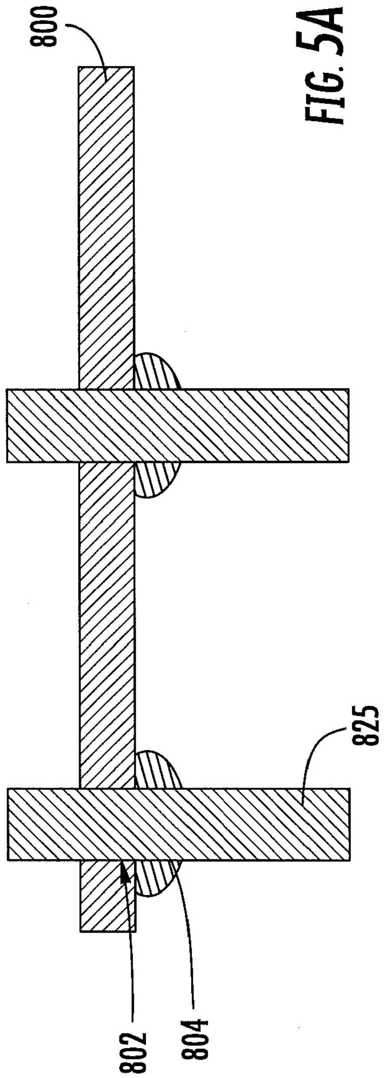


FIG. 5A

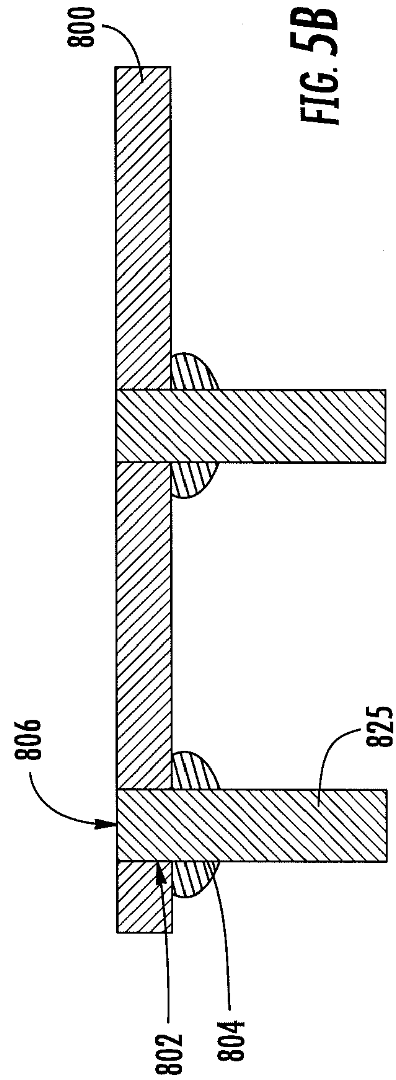


FIG. 5B

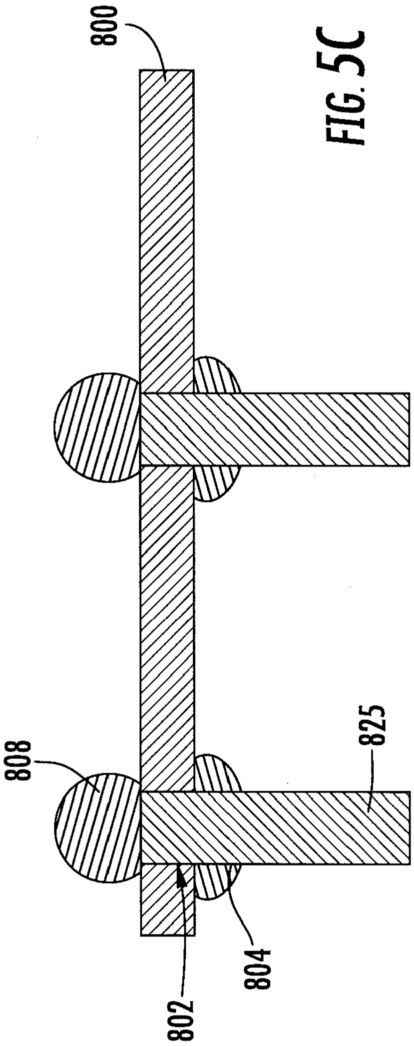


FIG. 5C

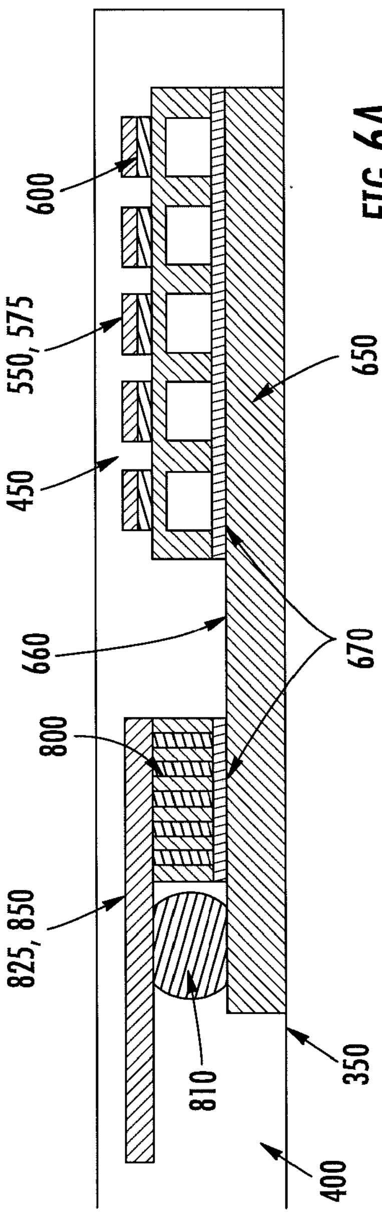

600
550, 575
450
660
670
800
825, 850
810
350
400
650

FIG. 6A

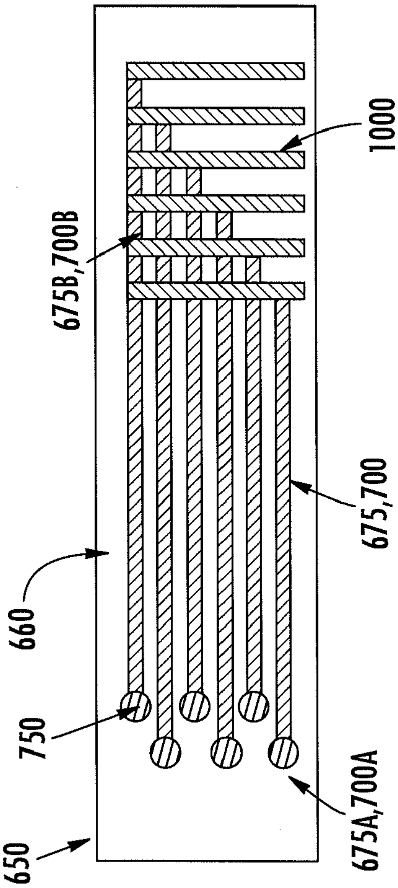

1000
675B,700B
660
675,700
750
650
675A,700A

FIG. 6B

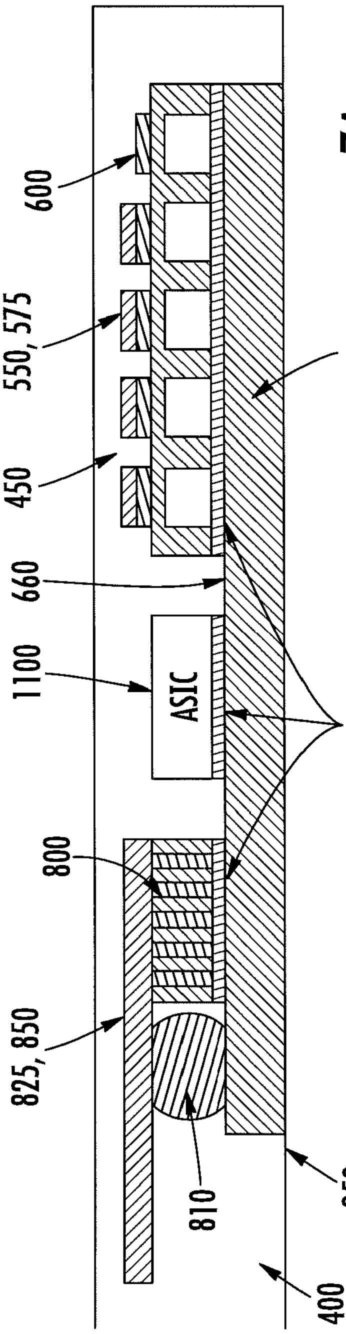

600
550, 575
450
660
1100
ASIC
800
825, 850
810
650
670
350
400

FIG. 7A

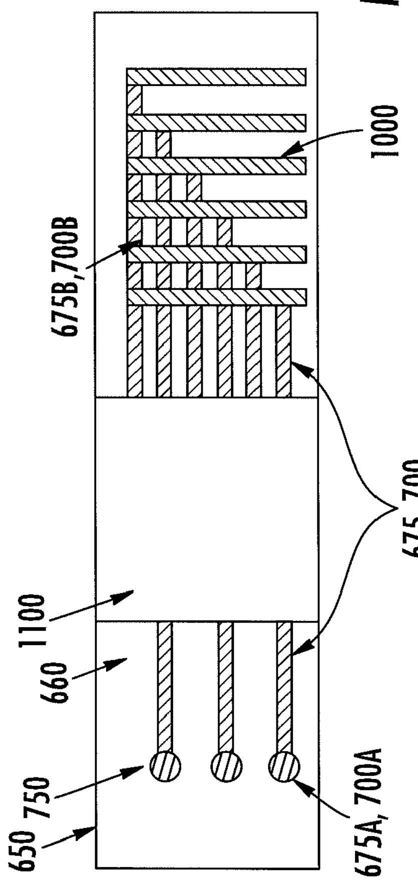

1000
675B, 700B
675, 700
1100
660
750
650
675A, 700A

FIG. 7B

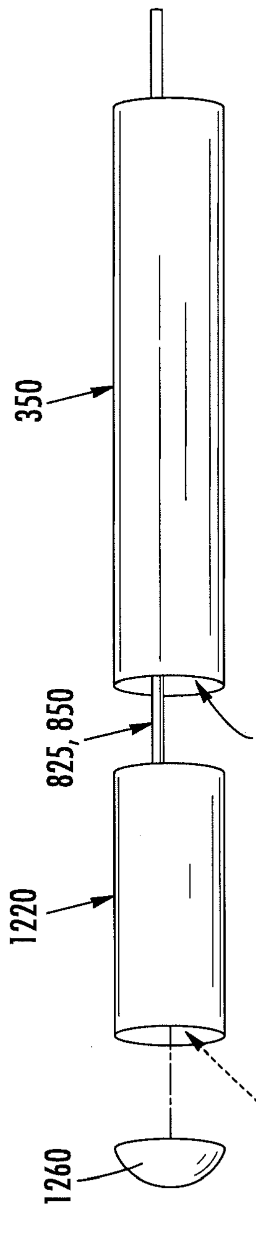


FIG. 8A

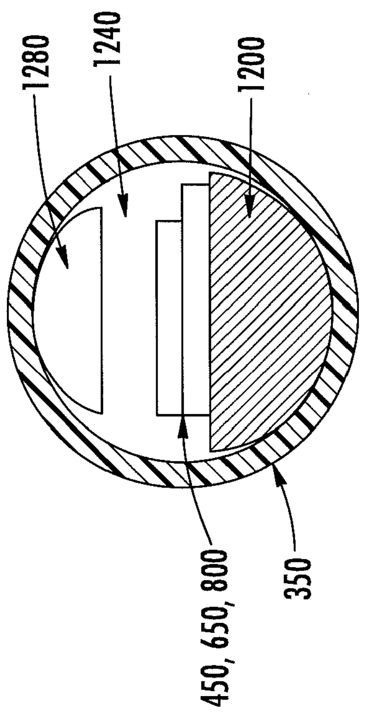


FIG. 8B

METHOD FOR FORMING AN ULTRASOUND DEVICE, AND ASSOCIATED APPARATUS

BACKGROUND OF THE DISCLOSURE

[0001] 1. Field of the Disclosure

[0002] Aspects of the present disclosure relate to ultrasonic transducers, and, more particularly, to a method of forming a connection with a laterally-facing piezoelectric micromachined ultrasonic transducer housed in a catheter, and associated ultrasound apparatus.

[0003] 2. Description of Related Art

[0004] Some micromachined ultrasonic transducers (MUTs) may be configured, for example, as a piezoelectric micromachined ultrasonic transducer (pMUT) as disclosed in U.S. Pat. No. 7,449,821 assigned to Research Triangle Institute, also the assignee of the present disclosure, which is also incorporated herein in its entirety by reference.

[0005] The formation of a pMUT device, such as the pMUT device defining an air-backed cavity as disclosed in U.S. Pat. No. 7,449,821, may involve the formation of an electrically-conductive connection between the first electrode (i.e., the bottom electrode) of the transducer device, wherein the first electrode is disposed on the front side of the substrate opposite to the air-backed cavity of the pMUT device, and the conformal metal layer(s) applied to the air-backed cavity for providing subsequent connectivity, for example, to an integrated circuit ("IC") or a flex cable.

[0006] In some instances, one or more pMUTs, for example, arranged in a transducer array, may be incorporated into the end of an elongate catheter or endoscope. In those instances, for a forward-looking arrangement, the transducer array of pMUT devices must be arranged such that the plane of the piezoelectric element of each pMUT device is disposed perpendicularly to the axis of the catheter/endoscope. This configuration may thus limit the lateral space about the transducer array, between the transducer array and the catheter wall, through which signal connections may be established with the front side of the substrate. Further, directing such signal connections laterally to the transducer array to the front side thereof, may undesirably and adversely affect the diameter of the catheter (i.e., a larger diameter catheter may undesirably be required in order to accommodate the signal connections passing about the transducer array).

[0007] Where the transducer array is a one-dimensional (1D) array, external signal connections to the pMUT devices may be accomplished by way of a flex cable spanning the series of pMUT devices in the transducer array so as to be in electrical engagement with (i.e., bonded to) each pMUT device via the conformal metal layer thereof. For instance, As shown in FIG. **1**A, in one exemplary 1D transducer array **100** (e.g., 1×64 elements), pMUT devices forming the array elements **120** may be attached directly to a flex cable **140**, with the flex cable **140** including one electrically-conductive signal lead per pMUT device, plus a ground lead. For a forward-looking transducer array, the flex cable **140** is bent about the opposing ends of the transducer array such that the flex cable **140** can be routed through the lumen of the catheter/endoscope which, in one instance, may comprise an ultrasound probe. However, for a forward-looking transducer array in a relatively small catheter/endoscope, such an arrangement may be difficult to implement due to the severe bend requirement for the flex cable (i.e., about 90 degrees), which may also be compounded by the number of conductors comprising the flex cable and the engagement of the electrically-conductive signal leads to the pMUT devices (also about a bend of about 90 degrees), in order for the transducer array to be disposed within the lumen of the catheter/endoscope.

[0008] Further, for a forward-looking two-dimensional (2D) transducer array, signal interconnection with the individual pMUT devices may also be difficult. That is, for an exemplary 2D transducer array (e.g. 14×14 to 40×40 elements), there may be many more required signal interconnections with the pMUT devices, as compared to a 1D transducer array. As such, more wires and/or multilayer flex cable assemblies may be required to interconnect with all of the pMUT devices in the transducer array. However, as the number of wires and/or flex cable assemblies increases, the more difficult it becomes to bend the larger amount of signal interconnections about the ends of the transducer device to achieve the 90 degree bend required to integrate the transducer array into a catheter/endoscope. In addition, the pitch or distance between adjacent pMUT devices may be limited due to the required number of wires/conductors. Accordingly, such limitations may undesirably limit the minimum size (i.e., diameter) of the catheter/endoscope that can readily be achieved.

[0009] Co-pending U.S. Patent Application No. 61/329,258 (Methods for Forming a Connection with a Micromachined Ultrasonic Transducer, and Associated Apparatuses; filed Apr. 29, 2010, and assigned to Research Triangle Institute, also the assignee of the present application), discloses improved methods of forming an electrically-conductive connection between a pMUT device and, for example, an integrated circuit ("IC"), a flex cable, or a cable assembly, wherein individual signal leads extend parallel to the operational direction of the transducer array or perpendicularly to the transducer array face to engage the respective pMUT devices in the transducer array (see generally, e.g., FIG. **1**B). Furthermore, the '258 application discloses that additional signal processing integrated circuits (IC's) can be integrated between the transducer array and the corresponding connective elements, thereby increasing the dimension of the transducer/connective element stack in a longitudinal direction of the disposition thereof in the catheter, but not increasing the lateral spacing around the transducer array, thus facilitating the configuration of the catheter to achieve a minimal diameter for a forward-looking transducer array configuration.

[0010] In the case of side- or lateral-looking transducer arrays, the transducer array is arranged such that the plane of the piezoelectric element of each transducer device is disposed in parallel to the axis of the catheter/endoscope. In such instances, there is relatively more lateral space about the transducer array, between the transducer array and the catheter wall, along the length of the transducer array, which may be used to attach connective elements thereto. However, the space between the back side of the transducer array and the catheter wall may be limited, particularly, for example, in catheters having an inner diameter of about 3 mm or less. Further, the previously-noted thicker stacks placed, for example, in a transducer element as illustrated in FIG. **1**B, and including a transducer array, signal processing IC's and connective elements, may not necessarily be feasible in instances of the limited catheter inner diameter. Such a configuration may also undesirably impart mechanical stresses to the signal lead (which must be bent about 90 degrees to be routed from the transducer and along the catheter) and/or the transducer array interface due to the thickness of the transducer/IC stack and the limited space available across the catheter diameter.

[0011] One particular example of a prior art side-looking ultrasound catheter transducer is shown in FIG. **2**, wherein a piezoelectric element **200** may be attached to a flex cable **210** using conductive epoxy **220**. A top electrode **230** and matching layer **240** may then be deposited on the piezoelectric element **200**, and the structure is then diced using a saw, wherein the cuts extend down to the flex cable **210** in order to form the elements of the transducer array **250**. An acoustic backing **260** may then be applied to the back of the flex cable **210**. However, such a configuration may be limited with respect to the number of transducer elements that can be practically implemented due, for instance to the resolution limit of the signal traces of the flex cable. For example, for a 3 mm catheter, only 16 traces with 100 μm pitch (plus ground strips on each side) may fit laterally within the lumen of the catheter. As such, an appropriate flex cable, such as a Siemens AcuNav flex cable with 64 elements, may undesirably have to be folded into 4 layers of 16 traces each (plus grounds) to connect all of the elements of a 64 element transducer array. Further, for 2D transducer arrays, high element counts (e.g., 196 to 1,600 elements) may require multilayer flex cabling for attachment and interconnection of all transducer elements, further increasing cost and complexity of the flex cabling. Multilayer flex cable could require up to 16 levels to connect all transducer elements due to limitations, for example, related to the pitch of conductor traces and inter-level vias in the flex cable (i.e., typically having a minimum of 100 μm pitch or more, depending on the number of levels). A multiple level flex cable may thus be undesirably expensive, difficult (or impossible) to manufacture, and may not be robust due to a relatively high probability of short circuits in light of the increased number of metal levels and vias. Other disadvantages of multilayer flex cabling may include higher conductor impedance, higher insertion loss, greater cross coupling between element traces, and higher shunt-to-ground capacitance which may reduce penetration depth compared to coaxial cabling (though typical coaxial cabling cannot be made with sufficiently fine pitch to be used in such catheter applications). Flex cabling may also be typically limited to segments of approximately 1 foot in length. Thus for a catheter that is 3 feet in total length, multiple flex cable segments must be serially connected in order to complete the electrical connection through the entire catheter, thereby undesirably increasing complexity and cost of assembly.

[0012] Thus, there exists a need in the ultrasonic transducer art, particularly with respect to a piezoelectric micromachined ultrasound transducer (“pMUT”), whether having an air-backed cavity or not, for improved methods of forming an electrically-conductive connection between the pMUT device and, for example, an integrated circuit (“IC”) and/or corresponding connective elements. In addition, it would be desirable to reduce the thickness of a chip stack containing the transducer array, IC devices and flex cabling, wiring and/or connective elements such that the chip stack may be accommodated within the relatively small diameter of a catheter or endoscope in a side looking configuration, for example, in cardiovascular devices, intravascular ultrasound devices, or laparoscopic surgery devices. Furthermore, it would be desirable to provide a method for forming electrical connections with a transducer array having a relatively higher transducer element count/density that is cost efficient (i.e., relatively low cost) and relatively manufacturable. Such solutions should desirably be effective for 2D transducer arrays, particularly 2D pMUT transducer arrays, but should also be applicable to 1D transducer arrays, in forward-looking and/or side looking arrangements, and should desirably allow greater scalability in the size of the probe/catheter/endoscope having such transducer arrays integrated therein.

BRIEF SUMMARY OF THE DISCLOSURE

[0013] The above and other needs are met by aspects of the present disclosure, wherein one such aspect relates to a method of forming an ultrasound device having an ultrasonic transducer apparatus comprising a transducer device defining a device plane, and including a piezoelectric material disposed between a first electrode and a second electrode. Such a method comprises engaging the ultrasonic transducer apparatus with a surface of an interposer device such that the device plane of the ultrasonic transducer apparatus is substantially parallel to the interposer device, wherein the interposer device is greater in at least one lateral dimension than the ultrasonic transducer apparatus so as to extend laterally outward thereof along the device plane upon engagement therewith, and comprises at least two conductors extending laterally therealong, with each conductor having opposed first and second ends. An electrically-conductive engagement is formed between each of the first and second electrodes and the first ends of the respective conductors, wherein at least one of the first and second ends of each conductor extends outwardly of a periphery of the ultrasonic transducer apparatus in the at least one greater lateral dimension of the interposer device. A connection support substrate is engaged with the interposer device about the second ends of the conductors and outwardly of the periphery of the ultrasonic transducer apparatus, wherein the connection support substrate has at least two connective elements operably engaged therewith, so as to form an electrically-conductive engagement between each connective element and the respective second ends of the conductors. The ultrasonic transducer apparatus, engaged with the interposer device and the connection support substrate, is then inserted into a lumen defined by a wall of a catheter member and about an end thereof, such that the device plane of the ultrasonic transducer apparatus extends parallel to the wall and such that the at least two connective elements extend along the lumen away from the end of the catheter member.

[0014] Another aspect of the present disclosure provides an ultrasound device, comprising an ultrasonic transducer apparatus including a transducer device defining a device plane, and having a piezoelectric material disposed between a first electrode and a second electrode. An interposer device has a surface configured to engage the ultrasonic transducer apparatus such that the device plane of the ultrasonic transducer apparatus is substantially parallel to the interposer device. The interposer device is greater in at least one lateral dimension than the ultrasonic transducer apparatus so as to extend laterally outward thereof along the device plane, and comprises at least two conductors extending laterally therealong, wherein each conductor has opposed first and second ends. The ultrasonic transducer apparatus is engaged with the interposer device so as to form an electrically-conductive engagement between each of the first and second electrodes and the first ends of the respective conductors, with at least one of the first and second ends of each conductor extending outwardly of a periphery of the ultrasonic transducer apparatus in the at least one greater lateral dimension of the interposer device. A connection support substrate is engaged with the interposer device about the second ends of the conductors and outwardly of the periphery of the ultrasonic transducer apparatus. The connection support substrate has at least two connective elements operably engaged therewith, and is engaged with the interposer device so as to form an electrically-conductive engagement between each connective element and the respective second ends of the conductors. A catheter member has a wall defining a lumen, wherein the lumen is configured to receive the ultrasonic transducer apparatus, engaged with the interposer device and the connection support substrate, about an end thereof, such that the device plane of the ultrasonic transducer apparatus extends parallel to the wall and such that the at least two connective elements extend along the lumen away from the end of the catheter member.

[0015] Aspects of the present disclosure thus address the identified needs and provide other advantages as otherwise detailed herein.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

[0016] Having thus described the disclosure in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

[0017] FIGS. **1**A and **1**B schematically illustrate a prior art arrangements for forming a connection with a forward-looking transducer apparatus disposed in a lumen;

[0018] FIG. **2** schematically illustrates a prior art arrangement for forming a connection with a side-looking transducer apparatus disposed in a lumen;

[0019] FIGS. **3** and **4** schematically illustrate an arrangement for forming a connection with a side-looking one-dimensional piezoelectric micromachined ultrasonic transducer array, according to one aspect of the disclosure;

[0020] FIGS. **5**A-**5**C schematically illustrate an arrangement for forming a connection support substrate for connection with a side-looking transducer apparatus, according to another aspect of the disclosure;

[0021] FIGS. **6**A and **6**B schematically illustrate side and top views of an arrangement for foliating a connection with a side-looking one- or two-dimensional piezoelectric micromachined ultrasonic transducer array, according to another aspect of the disclosure;

[0022] FIGS. **7**A and **7**B schematically illustrate side and top views of an arrangement for foliating a connection with a side-looking one- or two-dimensional piezoelectric micromachined ultrasonic transducer array, according to yet another aspect of the disclosure; and

[0023] FIGS. **8**A and **8**B schematically illustrate side and top views of a side-looking ultrasound apparatus, according to a further aspect of the disclosure.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0024] The present disclosure now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all aspects of the disclosure are shown. Indeed, the disclosure may be embodied in many different foams and should not be construed as being limited to the aspects set forth herein; rather, these aspects are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

[0025] A representative ultrasound device **300**, such as a catheter-based ultrasonic transducer array, is shown in FIG. **3**. Such an exemplary aspect of the present disclosure includes a catheter member **350** defining an axially-extending lumen **400**. In such an aspect, the lumen **400** houses an ultrasonic transducer apparatus **450**, such as one or more transducer devices, which may be arranged in the form of a one-dimensional or two-dimensional transducer array. The ultrasonic transducer apparatus **450** defines a device plane **500**, and each transducer device (see, e.g., FIGS. **6**A and **7**A) includes a piezoelectric material **550** disposed between a first electrode **575** and a second electrode **600**. An interposer device **650** may also be disposed within the lumen **400**. More particularly, the interposer device **650** includes a surface **660** configured to receive, engage and support the ultrasonic transducer apparatus **450** such that the device plane **500** of the ultrasonic transducer apparatus **450** is substantially parallel to the interposer device **650**. The ultrasonic transducer apparatus **450** may be secured to the surface **660**, for example, by a suitable adhesive or epoxy. In instances where the adhesive or other securement mechanism is involved in forming an electrically-conductive engagement between the ultrasonic transducer apparatus **450** and the surface **660**, a conductive material such as, for example, an anisotropically-conductive epoxy may be used to secure the ultrasonic transducer apparatus **450** to the surface **660** of the interposer device **650**. In some instances, the interposer device **650** may be comprised, for example, of silicon or other suitable material.

[0026] In one aspect, the interposer device **650** is greater in at least one lateral dimension than the ultrasonic transducer apparatus **450** (see, e.g., FIGS. **3** and **4**) so as to extend laterally outward thereof along the device plane **500**. In some instances, the interposer device **650** also includes at least two conductors **675**, **700** (See, e.g., FIGS. **4**, **6**B, and **7**B) extending laterally therealong, wherein the conductors **675**, **700** have opposed first ends **675**A, **700**A and second ends **675**B, **700**B. The ultrasonic transducer apparatus **450** is engaged with the interposer device **650** so as to faun an electrically-conductive engagement between each of the first and second electrodes **575**, **600** and the first ends **675**A, **700**A of the respective conductors **675**, **700**. In some aspects, either or both of the opposed ends of each conductor **675**, **700** may extend in conjunction with the interposer device **650**, outwardly of a periphery of the ultrasonic transducer apparatus **450** in the one or more greater lateral dimensions of the interposer device **650**. That is, upon engagement of the ultrasonic transducer apparatus **450** with the interposer device **650**, the interposer device **650** will extend outwardly of the periphery of the ultrasonic transducer apparatus **450** in at least one lateral direction. As such, either or both of the conductors **675**, **700** may have one end thereof extending through the interposer device **650** to the interface between the interposer device **650** and the ultrasonic transducer apparatus **450**, so as to form the electrically-conductive connection with the ultrasonic transducer apparatus **450**, wherein such an aspect is disclosed in further detail herein.

[0027] In other aspects, either or both of the conductors **675**, **700** may have one end thereof extending through the interposer device **650** so as to be exposed with respect to the surface of the interposer device **650** with which the ultrasonic transducer apparatus **450** is engaged, but outside the periphery of the ultrasonic transducer apparatus **450**. In such instances, the electrodes **575**, **600** may be electrically-engaged with the first end(s) **675**A, **700**A of the conductors **675**, **700** by way of discrete conductive elements (not shown) engaged therebetween to respective wirebond pads **250**A, **250**B such as, for example in a wire bonding process. Further, in some aspects, the ultrasonic transducer apparatus **450** (i.e., pMUT), may or may not include metalized through-substrate interconnects connecting the first electrode **575** to the back side of the substrate. Accordingly, as shown in FIG. **4**, in some aspects, the signal and ground traces of the transducer devices of the ultrasonic transducer apparatus **450** may be routed to the peripheral edges of the ultrasonic transducer apparatus **450** (i.e., into electrically-conductive engagement with wirebond pads **250**A, **250**B) and wirebonded to corresponding wirebond pads **250**A, **250**B in electrically-conductive engagement with the first and second conductors **675**, **700** associated with the interposer device **650**. Using such a configuration of the ultrasonic transducer apparatus **450**, fewer photomask levels, for example, are used to fabricate the transducer devices, thus reducing fabrication costs. However, the footprint (lateral area) of the ultrasonic transducer apparatus **450** may be required to be larger to accommodate the wirebond pads. For instance, a 2 mm wide ultrasonic transducer device **450** (without metalized through-substrate interconnects) would require about a 2.8 mm to about a 3 mm wide interposer device **650**, which would fit within the lumen of a 12 French (4 mm O.D.) catheter. However, using metalized through-substrate interconnects, instead of a wirebond pad configuration, such that an electrically-conductive engagement is formed with the conductors **675**, **700** associated with the interposer device **650** by way of the conductive layer associated with the air-backed cavities of the transducer devices, the width of the ultrasonic transducer device **450** could be reduced to between about 1.7 mm and about 1.8 mm, and the interposer device **650** could also have substantially the same width, since the additional width required for wirebond pads is eliminated. In such an instance, the implementation of transducer devices with metalized through-substrate interconnects would reduce the required catheter size to 8 French (2.7 mm O.D.).

[0028] As disclosed, the ultrasonic transducer apparatus **450** may be secured to the surface **660**, for example, by a bonding material **670** such as a suitable adhesive or epoxy. In instances where the adhesive or other securement mechanism is involved in forming an electrically-conductive engagement between the ultrasonic transducer apparatus **450** and the surface **660**, a conductive material such as, for example, an anisotropically-conductive epoxy may be used to secure the ultrasonic transducer apparatus **450** to the surface **660** of the interposer device **650**. In some instances, it may be desirable to implement an acoustically-absorbent epoxy such as, for example, a tungsten-filled epoxy, to secure the ultrasonic transducer apparatus **450** to the interposer device **650**, which may also provide an acoustic backing for the transducer devices. If the ultrasonic transducer device **450** is wirebonded to the conductors **675**, **700** associated with the interposer device **650**, a potting epoxy may be used to cover the wirebond connections.

[0029] In some aspects, the conductors **675**, **700** extend laterally with respect to the interposer device **650** such that the second ends **675**B, **700**B thereof are in electrically-conductive engagement with an array of electrically-conductive pads **750** (see, e.g., FIG. **4**), wherein the interposer device **650** is configured to receive and engage a connection support substrate **800** such that the second ends **675**B, **700**B of the conductors **675**, **700**, via the pads **750**, engage (in an electrically-conductive engagement) corresponding connective elements **825**, **850** (see, e.g., FIG. **3**) engaged with and supported by the connection support substrate **800** outwardly of the periphery of the ultrasonic transducer apparatus **450**. The connective elements **825**, **850** may comprise, for example, external signal leads for the ultrasonic transducer apparatus **450**. As such, in some aspects, the ultrasonic transducer apparatus **450**, engaged with the interposer device **650** and the connection support substrate **800**, is configured to be received in an end portion of the lumen **400** defined by a wall of the catheter member **350**, such that the device plane **500** of the ultrasonic transducer apparatus **450** extends parallel to the wall or axis of the catheter member **350** and such that the at least two connective elements **825**, **850** extend along the lumen **400** away from the end of the catheter member **350** (i.e., so as to form a "side-looking" ultrasound device).

[0030] In some instances, the conductors **675**, **700** associated with the interposer device **650** may be of different lengths due to the location and configuration of the corresponding wirebond pad with respect to the pads **750** for connecting with the connective elements **825**, **850**. As such, in some instances, the conductors **675**, **700** associated with the interposer device **650** may be configured to have varying widths, or otherwise varying cross-sectional dimensions, such that differences between the electrical resistances of the conductors **675**, **700** are minimized or substantially eliminated. That is, the conductors **675**, **700** may be configured so as to achieve and maintain substantially constant impedance with respect to the signal leads extending to each transducer device of the ultrasonic transducer apparatus **450**.

[0031] In some aspects, the connection support substrate **800** may be configured, for instance, to be compatible with a flip-chip aligner-bonder for facilitating engagement with the interposer device **650** supporting the ultrasonic transducer apparatus **450**. As such, the interposer device **650** may advantageously be configured such that the arrangement of connective elements **825**, **850** with respect to the connection support substrate **800** is not required to correspond to the arrangement of transducer devices in the array implemented by the ultrasonic transducer apparatus **450**. For example, the pitch and/or gauge of the connective elements **825**, **850** may be different from the pitch or electrode area of the transducer devices, wherein correspondence may be achieved, if necessary or desired, by appropriately configuring the conductors **675**, **700** associated with the interposer device **650**, as will be appreciated by one skilled in the art. Such a configuration of the interposer device **650** may be advantageous, for example, with respect to side-looking 1D (one-dimensional) arrays or ultrasonic transducer apparatuses **450**. For instance, as shown in FIG. **4**, a 5×16 array of wires/connective elements may be engaged with a 1×64 array of transducer devices in an ultrasonic transducer apparatus **450** through appropriate arrangement of the conductors associated with the interposer device **650**. Accordingly, the implementation of such an interposer device may provide additional flexibility in the selection of cabling used (i.e., in the number of wires or connective elements per cable, as well as the wire pitch) for connection with the ultrasonic transducer apparatus **450**, and may also allow the attachment of a wire/connective element array with larger number of wires (e.g., 8×16 or 128 wires) to provide additional ground leads to be interspersed between signal elements/wires to reduce noise and cross-talk between conductive elements.

[0032] FIG. **5**A schematically illustrates another aspect of the present disclosure directed to the formation of the connection support substrate **800** and subsequent connection thereof to the interposer device **650**. More particularly, the connection support substrate **800** (comprised, for example, of silicon) is first etched, for example, using a DRIE process, to define a via **802** extending therethrough with sidewalls substantially perpendicular to the etched surface. The connection support substrate **800** may then be thermally oxidized to provide electrical isolation between adjacent vias (not shown). One of the connective elements (e.g., element **825**) is then inserted into the via **802** so as to extend therethrough, and the connective element **825** then bonded to the connection support substrate **800** with a bonding material **804**, such as a non-conductive epoxy, applied around the connective element **825** on the surface of the connection support substrate **800** opposite the surface of the connection support substrate **800** through which the connective element **825** extends. For example, fine gauge (e.g., 40-50 AWG) wire may be fed into the via and then potted within the via with a low-viscosity epoxy in a vacuum chamber to fill the voids. In some instances, the connective element **825** may comprise an elongate conductor circumscribed by an insulator. In such instances, the insulator may be configured to provide electrical isolation between the conductor/connective element **825** and the connection support substrate **800**. In other instances, if the connective element **825** does not include the insulator, an insulator material (not shown) may be first deposited on the connection support substrate **800** so as to extend through the via **802**, so as to electrically isolate the connective element **825** from the connection support substrate **800**.

[0033] As shown in FIG. **5**B, once the connective element **825** is secured to the connection support substrate **800**, the surface of the connection support substrate **800** through which the connective element **825** extends is planarized, for example, by a mechanical polishing process or a chemical-mechanical polishing (CMP) process to produce a substantially planar surface having the end **806** of the connective element **825** exposed. In some instances, any gap between the connective element **825** and the wall defining the via **802** can be filled, for example, with a non-conductive epoxy to provide a void-free, planar surface of the connection support substrate **800** for subsequent processing. For instance, one aspect implements a microribbon cable, which includes individually insulated 46-48 AWG Cu wires with a Cu backplane under each ribbon to reduce cross talk. The microribbon cable can be fed one row at a time into the connection support substrate **800** rather than individual wires being guided into individual vias. The connective element **825** and/or the connection support substrate **800** is subsequently bonded to the interposer device **650** and/or the pads **750** associated therewith. In one such aspect, the conductive bonding material **808** may comprise, for example, a solder bump, as shown in FIG. **5**C. In such instances, the bonding may be effectuated by reflowing the solder comprising the solder bump. In another aspect, the conductive bonding material **808** may comprise a metal (i.e., Au, Al, or Cu) or plated metal stud bumps formed using a wire bonder or by electroplating, wherein such stud bumps can be thermo-compression bonded to provide the electrically-conductive engagement through direct metal bonding. An anisotropic conductive epoxy may also be implemented as the conductive bonding material **808**. Alignment of the connective elements **825**, **850** associated with the connection support substrate **800** with the pads **750** associated with the interposer device **650** can be accomplished, for example, using a flip-chip aligner-bonder. Once bonded to the pads **750**, the connective elements **825**, **850** are bent about 90 degrees so as to extend substantially parallel to the device plane **500** (but such that the interface between the pads **750** and the connective elements **825**, **850** extends perpendicularly to the device plane **500**) so as to extend along the lumen **400** of the catheter member **350**, as shown, for example, in FIGS. **6**A and **7**A. In some aspects, a strain relief element **810**, such as additional epoxy, as shown, for instance, in FIGS. **6**A and **7**A may be applied between the connective elements **825**, **850** and the interposer device **650** for relieving strain on the interface between the connection support substrate **800** and the interposer device **650** (as well as the interface between the pads **750** and the connective elements **825**, **850**).

[0034] Other aspects of the present disclosure are provided in FIGS. **6**A and **6**B, wherein the ultrasonic transducer apparatus **450** may comprise, for example, a vertically-integrated 1D or 2D transducer array (i.e., pMUT transducer devices with through-substrate interconnects). In such instances, both the first and second electrodes **575**, **600** may be accessible with respect to one surface of the ultrasonic transducer apparatus **450**. Accordingly, the ultrasonic transducer apparatus **450** may be directly engaged (i.e., without wirebonding) with the interposer device **650**, without requiring the additional area or larger lateral dimension (with respect to both the ultrasonic transducer apparatus **450** and the interposer device **650**) for wirebond pads and associated routing of conductors associated therewith. In such instances, the interposer device **650** may further comprise at least one electrically-conductive trace **1000** engaged with the surface **660** of the interposer device **650**, wherein the trace(s) **1000** are configured to be in electrically-conductive engagement with the first ends **675**A, **700**A of the respective conductors **675**, **700**.

[0035] In some aspects, the ultrasonic transducer apparatus **450** may be engaged with the interposer device **650** such that an electrically-conductive engagement is formed between one of the first and second electrodes **575**, **600** and the corresponding trace(s) **1000** using a bonding material **670** such as, for example, a conductive solder element, a conductive stud element, and a conductive bonding material disposed therebetween. For instance, the ultrasonic transducer apparatus **450** can be engaged with the surface **660** of the interposer device **650** using an anisotropic conductive epoxy, solder bumps, gold stud bumps or direct-plated metal bonding. The connection support substrate **800** may be engaged with the interposer device **650** in a similar manner via a bonding material **670** so as to form the electrically-conductive engagement between the conductors **675**, **700** and the connective elements **825**, **850**.

[0036] Since, in some aspects, the interposer device **650** may be comprised of silicon, the conductors **675**, **700** and/or the trace(s) **1000** may be formed using various semiconductor processing techniques, as will be appreciated by one skilled in the art. For example, conductive material may be deposited on the interposer device **650** and patterned by photolithography and etching, or lift-off processing. Once the conductive material is deposited and the conductors **675**, **700** and/or the trace (s) **1000** formed, an insulator such as SiO_2 may be selectively deposited over the conductors **675**, **700** and/or the trace(s) **1000** so as to prevent lateral electrical conduction, for instance, when an anisotropic conductive epoxy is used to engage the ultrasonic transducer apparatus **450** with the interposer device **650**. In other instances, the deposition of the insulator over the conductors **675**, **700** and/or the trace(s) **1000** may also prevent electrical conduction between the portions of the conductors **675**, **700** and/or the trace(s) **1000** extending along the interposer device **650** under the interface between the ultrasonic transducer apparatus **450** and the interposer device **650**.

[0037] The pads **750**, conductors **675**, **700**, and trace(s) **1000** may be formed as different metallization levels with respect to the interposer device **650**, with an insulator deposited between levels for electrical isolation. For example, the conductors **675**, **700** connecting the pads **750** to the trace(s) **1000** may be formed as a first metallization level within the interposer device **650**, while the pads **750** and/or the trace(s) **1000** may be formed as a second metallization level that may remain exposed about the surface **660**. The exposed portions of the trace(s) **1000** may be implemented for direct connection to one of the electrodes of the ultrasonic transducer apparatus **450** or, in the case of a pMUT having an air-backed cavity, the electrodes **575**, **600** on one side of the ultrasonic transducer apparatus **450**. In some instances, connection of the second electrode **600** to the trace(s) **1000** could be accomplished by way of a conformal metallization layer deposited in the via comprising the air-backed cavity of the pMUT (not shown). In other instances, the smaller exposed pads (not shown) could be provided at the second ends **675**B, **700**B of the conductors **675**, **700**, wherein a transducer device of the ultrasonic transducer apparatus **450** could be electrically-engaged with the conductors **675**, **700** via the small pads. In some instances, the small exposed pads could comprise a portion of the respective conductors, and may eliminate multiple level metallization requirements. However, in some aspects, as the required number of signal leads increases, it may be advantageous to include multiple levels of metallization within the interposer device **650**. For example, for a 2D transducer array, 3-4 metallization levels associated with the interposer device **650** may be required for a transducer element count of between about 200 and about 400 elements, which may be advantageous, for instance, over a flex cable approach for connection to a 2D transducer array comprising the ultrasonic transducer device **450**, which may require up to 16 flex cable levels due to the limitations of the available conductor pitch, typically on the order of 100 μm. In this regard, a 16-level multilayer flex cable may be too expensive, difficult to manufacture, and may not be sufficiently robust due to high probability of shorts. Smaller conductor pitch of between about 10 μm and about 50 μm could be fabricated, for example, on a silicon interposer device using silicon photolithography techniques having improved resolution.

[0038] In some aspects, as shown in FIGS. **7**A and **7**B, the ultrasonic transducer device **450** (i.e., a pMUT transducer device) disclosed herein, as necessary or desired, may be engaged with an IC or integrated circuit (e.g., a control IC such as an amplifier, multiplexer, or beam former) **1100**, for example, via the interposer device **650**. For instance, the IC **1100** could be engaged with the interposer device **650**/conductors **675**, **700**, between the ultrasonic transducer device **450** and the connection support substrate **800** using, for example, solder bumps, gold stud bumps, metal stud bumps, anisotropic conductive epoxy, or other suitable electrically-conductive connection provisions. In one example, the IC **1100** may be configured as an application specific integrated circuit (ASIC), and the interposer device **650** may thus be configured to facilitate the integration of the ASIC within close proximity to the ultrasonic transducer apparatus **450**. ASIC functions that could be integrated with respect to the IC **1100** in engagement with the interposer device **650** include, for example, amplification to enhance the small receive voltages generated by the transducer (pMUT) elements/devices within the array, multiplexing or switching for toggling transducer elements/devices between transmit mode and receive mode, timing or beam forming for facilitating receipt of the receive signals by the ultrasound system, and/or multiplexing of transmit and receive channels to reduce the number of required conductors from one element per conductor to multiple elements per conductor. In other instances, the IC **1100** may be configured as charge pump transmit circuits for generating relatively higher transmit voltages from a relatively small control signal sent from the ultrasound system (for example, the IC **1100** may comprise a multiplexer, an amplifier, a beam former, and/or a high voltage transmit circuit). Such ASIC functions may improve the performance of the ultrasonic transducer apparatus **450** (e.g., amplify receive signals prior to transmission on high-capacitance system cabling) and/or reduce the number of connective elements required to be housed within the catheter (e.g., 4:1 or 8:1 multiplexing of element transmit and/or receive signals by an appropriately-configured IC **1100**). In such aspects, the interposer device **650** and the conductors **675**, **700** therein, may be configured similarly to the arrangement for receiving the ultrasonic transducer apparatus **450** (i.e., with exposed conductive pads in communication with the conductors **675**, **700**), in order to facilitate integration of the IC **1100** (or multiple IC's) in communication with the ultrasonic transducer apparatus **450** and the pads **750**/connective elements **825**, **850** via the connection support substrate **800**.

[0039] Many modifications and other aspects of the disclosures set forth herein will come to mind to one skilled in the art to which these disclosures pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. For example, the exemplary methods and aspects thereof as disclosed herein may also have related apparatuses associated therewith, as otherwise disclosed herein. As such, the apparatuses and methods disclosed herein may be suitably adapted to address such instances, within the scope of the present disclosure. Further, in another aspect regarding transducer (pMUT) arrays in a side-looking catheter, as shown in FIGS. **8**A and **8**B, the ultrasonic transducer apparatus **450**, interposer device **650**, and connection support substrate **800** may be mounted on a catheter mount **1200** inside a catheter transducer tip **1220**, which may be configured (sized) to house the interposer device **650** and the connection support substrate **800** lengths (i.e., ~2 cm). For example, the interposer device **650** may be about 14.5 mm in length for a 64 element 1D transducer (pMUT) array, wherein the array length may be about 10.5 mm. For a 2D transducer (pMUT) array with ~200 elements and 2 mm×2 mm size, the interposer device **650** could be about 6 mm in length. The catheter transducer tip **1220** may be sealed at the opposing distal and proximal ends thereof, while being filled with an acoustic coupling fluid **1240** such as, for example, glycerin, polyethylene glycol or silicone oil. The conductive elements (i.e., microribbon or other cabling) extends through the proximal end of the catheter transducer tip **1220** and along the lumen **400** defined by the catheter member **350**, and may terminate at an electronic device, such as a circuit board (not shown), about the proximal end of the catheter member **350**. About the distal end of the catheter member **350**, a rounded catheter cap **1260** may be engaged with or formed in the catheter transducer tip **1220** in order to facilitate insertion of the catheter member **350** during the medical procedure, such as an intracardiac or intravascular imaging process. The catheter transducer tip **1220** may also include an acoustic lens **1280** engaged with the wall of the catheter member **350** defining the lumen **400**, opposite to the ultrasonic transducer apparatus **450**. A passive lens may be implemented to improve image resolution for 1D transducer arrays (i.e., 1 element only in elevation), since such 1D arrays may not be capable of elevation focusing, whereas a 2D transducer array may have elevation focusing capabilities, which may thus not require a lens. The catheter member **350** may be comprised, for example, of Pebax™ or any other suitable materials exhibiting, for instance, low acoustic impedance and low absorption, which may be particularly beneficial for the wall of the catheter transducer tip **1220**, which requires acoustic transmission capabilities for the ultrasonic transducer apparatus **450**. The remaining portion of the catheter member **350** may also be comprised of Pebax™ or other suitable material exhibiting an appropriate elastic modulus and/or Shore hardness, for example, to provide flexibility near the distal catheter tip for steerability of the tip and rigidity in the catheter shaft proximal to the tip for pushability of the catheter member **350** through the body of the patient. Therefore, it is to be understood that the disclosures are not to be limited to the specific aspects disclosed and that modifications and other aspects are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

That which is claimed:

1. A method of forming an ultrasound device having an ultrasonic transducer apparatus comprising a transducer device defining a device plane, and including a piezoelectric material disposed between a first electrode and a second electrode, said method comprising:

engaging the ultrasonic transducer apparatus with a surface of an interposer device such that the device plane of the ultrasonic transducer apparatus is substantially parallel to the interposer device, the interposer device being greater in at least one lateral dimension than the ultrasonic transducer apparatus so as to extend laterally outward thereof along the device plane upon engagement therewith, and comprising at least two conductors extending laterally therealong, each conductor having opposed first and second ends;

forming an electrically-conductive engagement between each of the first and second electrodes and the first ends of the respective conductors, at least one of the first and second ends of each conductor extending outwardly of a periphery of the ultrasonic transducer apparatus in the at least one greater lateral dimension of the interposer device; and

engaging a connection support substrate with the interposer device about the second ends of the conductors and outwardly of the periphery of the ultrasonic transducer apparatus, the connection support substrate having at least two connective elements operably engaged therewith, so as to form an electrically-conductive engagement between each connective element and the respective second ends of the conductors.

2. A method according to claim **1**, further comprising inserting the ultrasonic transducer apparatus, engaged with the interposer device and the connection support substrate, into a lumen defined by a wall of a catheter member and about an end thereof, such that the device plane of the ultrasonic transducer apparatus extends parallel to the wall and such that the at least two connective elements extend along the lumen away from the end of the catheter member.

3. A method according to claim **1**, further comprising engaging the transducer device with a device substrate to form the ultrasonic transducer apparatus, the transducer device being configured with the first and second electrodes extending laterally with respect to the device substrate and to respective bond pads disposed about a periphery thereof.

4. A method according to claim **3**, wherein engaging the ultrasonic transducer apparatus with a surface of an interposer device further comprises engaging the ultrasonic transducer apparatus with a surface of an interposer device with a non-conductive adhesive material disposed therebetween.

5. A method according to claim **3**, wherein foaming an electrically-conductive engagement further comprises engaging a conductive member between the bond pads associated with each of the first and second electrodes and the first ends of the respective conductors.

6. A method according to claim **1**, wherein the transducer device is disposed on a substrate and in communication with through-substrate interconnects, and wherein forming an electrically-conductive engagement further comprises forming an electrically-conductive engagement between each of the first and second electrodes and the first ends of the respective conductors via the through-substrate interconnects.

7. A method according to claim **6**, wherein forming an electrically-conductive engagement between each of the first and second electrodes and the first ends of the respective conductors via one of a conductive solder element, a conductive stud element, and a conductive bonding material between the through-substrate interconnects and the first ends of the respective conductors.

8. A method according to claim **1**, further comprising engaging the at least two connective elements with a connection support substrate, with the at least two connective elements inserted into and extending through respective vias defined by the connection support substrate, prior to engaging the connection support substrate with the interposer device.

9. A method according to claim **8**, further comprising depositing an insulator material on the connection support substrate such that the insulator material extends along the vias defined thereby, prior to engaging the at least two connective elements with the connection support substrate.

10. A method according to claim **1**, wherein engaging a connection support substrate with the interposer device comprises engaging a connection support substrate with the interposer device with one of a conductive solder element, a conductive stud element, and a conductive bonding material therebetween, so as to form an electrically-conductive engagement between each connective element and the respective second ends of the conductors.

11. A method according to claim **1**, wherein engaging the connection support substrate with the interposer device further comprises engaging the connection support substrate with the interposer device such that the electrically-conductive engagement between each connective element and the respective second ends of the conductors extends substantially perpendicularly to the device plane of the ultrasonic transducer apparatus.

12. A method according to claim **1**, further comprising engaging a strain relief device between the at least two connective elements and the interposer device so as to relieve strain on the electrically-conductive engagement between each connective element and the respective second ends of the conductors.

13. A method according to claim **1**, wherein the interposer device further comprises at least one electrically-conductive trace engaged with the surface of the interposer device and in electrically-conductive engagement with the first ends of the respective conductors, and wherein forming an electrically-conductive engagement further comprises forming an electrically-conductive engagement between one of the first and second electrodes and the at least one trace with a conductive bonding material therebetween upon engaging the ultrasonic transducer apparatus with the surface of the interposer device.

14. A method according to claim **13**, further comprising engaging at least one integrated circuit device with the interposer device between the ultrasonic transducer apparatus and connection support substrate, such that the at least one integrated circuit device is in electrically-conductive communication with at least one of the conductors.

15. A method according to claim **14**, wherein engaging an integrated circuit device with the interposer device further comprises forming an electrically-conductive engagement between the integrated circuit device and the at least one trace with one of a conductive solder element, a conductive stud element, and a conductive bonding material therebetween.

16. A method according to claim **1**, further comprising varying a cross-sectional dimension of each of the at least two conductors extending through the interposer device such that a resistance of each of the at least two conductors is substantially the same.

17. An ultrasound device, comprising:

an ultrasonic transducer apparatus comprising a transducer device defining a device plane, and including a piezoelectric material disposed between a first electrode and a second electrode:

an interposer device having a surface configured to engage the ultrasonic transducer apparatus such that the device plane of the ultrasonic transducer apparatus is substantially parallel to the interposer device, the interposer device being greater in at least one lateral dimension than the ultrasonic transducer apparatus so as to extend laterally outward thereof along the device plane, and comprising at least two conductors extending laterally therealong, each conductor having opposed first and second ends, the ultrasonic transducer apparatus being engaged with the interposer device so as to form an electrically-conductive engagement between each of the first and second electrodes and the first ends of the respective conductors, with at least one of the first and second ends of each conductor extending outwardly of a periphery of the ultrasonic transducer apparatus in the at least one greater lateral dimension of the interposer device;

a connection support substrate engaged with the interposer device about the second ends of the conductors and outwardly of the periphery of the ultrasonic transducer apparatus, the connection support substrate having at least two connective elements operably engaged therewith, the connection support substrate being engaged with the interposer device so as to form an electrically-conductive engagement between each connective element and the respective second ends of the conductors.

18. A device according to claim **17**, further comprising a catheter member having a wall defining a lumen, the lumen being configured to receive the ultrasonic transducer apparatus, engaged with the interposer device and the connection support substrate, about an end thereof such that the device plane of the ultrasonic transducer apparatus extends parallel to the wall and such that the at least two connective elements extend along the lumen away from the end of the catheter member.

19. A device according to claim **17**, wherein the ultrasonic transducer apparatus further comprises a device substrate engaged with the transducer device, and wherein the transducer device is configured with the first and second electrodes extending laterally with respect to the device substrate and to respective bond pads disposed about a periphery thereof.

20. A device according to claim **19**, wherein the ultrasonic transducer apparatus is engaged with the surface of the interposer device with a non-conductive adhesive material disposed therebetween.

21. A device according to claim **19**, further comprising a conductive member engaged between the bond pads associated with each of the first and second electrodes and the first ends of the respective conductors, and forming the electrically-conductive engagement therebetween.

22. A device according to claim **17**, wherein the transducer device is disposed on a substrate and in communication with through-substrate interconnects, and wherein the through-substrate interconnects are configured to form an electrically-conductive engagement between each of the first and second electrodes and the first ends of the respective conductors.

23. A device according to claim **22**, wherein the through-substrate interconnects are engaged with the first ends of the respective conductors with one of a conductive solder element, a conductive stud element, and a conductive bonding material therebetween.

24. A device according to claim **17**, wherein the at least two connective elements are configured to be inserted into and to extend through respective vias defined by the connection support substrate.

25. A device according to claim **24**, further comprising an insulator material deposited on the connection support substrate such that the insulator material extends along the vias defined thereby.

26. A device according to claim **17**, wherein the connection support substrate is engaged with the interposer device with one of a conductive solder element, a conductive stud element, and a conductive bonding material therebetween, the one of the conductive solder element, the conductive stud element, and the conductive bonding material foaming an electrically-conductive engagement between each connective element and the respective second ends of the conductors.

27. A device according to claim **17**, wherein the connection support substrate is engaged with the interposer device such that the electrically-conductive engagement between each connective element and the respective second ends of the conductors extends substantially perpendicularly to the device plane of the ultrasonic transducer apparatus.

28. A device according to claim **17**, further comprising a strain relief device engaged between the at least two connective elements and the interposer device so as to relieve strain on the electrically-conductive engagement between each connective element and the respective second ends of the conductors.

29. A device according to claim **17**, wherein the interposer device further comprises at least one electrically-conductive trace engaged with the surface of the interposer device and in electrically-conductive engagement with the first ends of the respective conductors, and wherein one of the first and second electrodes is arranged in electrically-conductive engagement with the at least one trace with a conductive bonding material disposed therebetween.

30. A device according to claim **29**, further comprising at least one integrated circuit device engaged with the interposer device between the ultrasonic transducer apparatus and connection support substrate, such that the at least one integrated circuit device is in electrically-conductive communication with at least one of the conductors.

31. A device according to claim **30**, wherein the at least one integrated circuit comprises one of a multiplexer, an amplifier, a beamformer, and a high voltage transmit circuit.

32. A device according to claim **30**, wherein the integrated circuit device is arranged in electrically-conductive engagement with the at least one trace with one of a conductive solder element, a conductive stud element, and a conductive bonding material therebetween.

33. A device according to claim **17**, wherein each of the at least two conductors extending through the interposer device is configured to include a varied cross-sectional dimension such that a resistance of each of the at least two conductors is substantially the same.

* * * * *

patsnap

专利名称(译)	用于形成超声装置的方法和相关装置		
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当前申请(专利权)人(译)	三角研究所		
[标]发明人	DAUSCH DAVID CARLSON JAMES GILCHRIST KRISTIN HEDGEPATH		
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摘要(译)

提供了一种用于形成与超声换能器设备（UTA）的连接的方法和设备，该超声换能器设备包括具有第一和第二电极的换能器设备。 UTA与插入器设备表面接合。内插器装置在至少一个横向尺寸上比在UTA的横向外侧延伸，并且包括至少两个横向延伸的导体。在第一和第二电极与导体的相应第一端之间形成导电接合。连接支撑基板围绕导体的第二端与插入器装置接合，并且包括至少两个连接元件，用于与导体的相应第二端形成导电接合。然后将UTA插入导管构件内腔中，使得UTA的装置平面和至少两个连接元件沿内腔轴向延伸。