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(54) ULTRASOUND SCANNER BUILT WITH CAPACITIVE MICROMACHINED ULTRASONIC TRANSDUCERS (CMUTS)

(76) Inventor: Yongli Huang, San Jose, CA (US)

Correspondence Address:
LEE & HAYES, PLLC
601 W. RIVERSIDE AVENUE, SUITE 1400
SPOKANE, WA 99201 (US)

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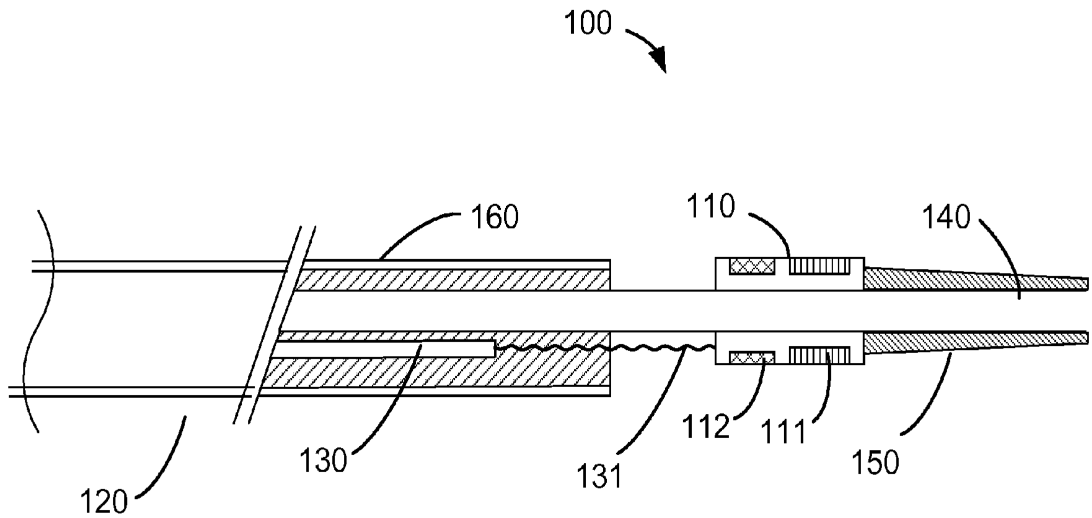
(57) ABSTRACT

Ultrasonic scanners and methods of manufacturing ultrasonic scanners. One embodiment of a method includes integrating a flexible electronic device (e.g. an IC) and a flexible ultrasonic transducer (e.g. a portion of a circular CMUT array) with a flexible member. The IC, the transducer, and the flexible member can form a flexible subassembly which is rolled up to form an ultrasonic scanner. The integration of the IC and the transducer can occur at the same time. In the alternative, the integration of the electronic device can occur before the integration of the transducer. Moreover, the integration of the transducer can include using a semiconductor technique. Furthermore, the rolled up subassembly can form a lumen or can be attached to a lumen. The method can include folding a portion of the flexible subassembly to form a forward looking transducer. The flexible member of some subassemblies can include a pair of arms.



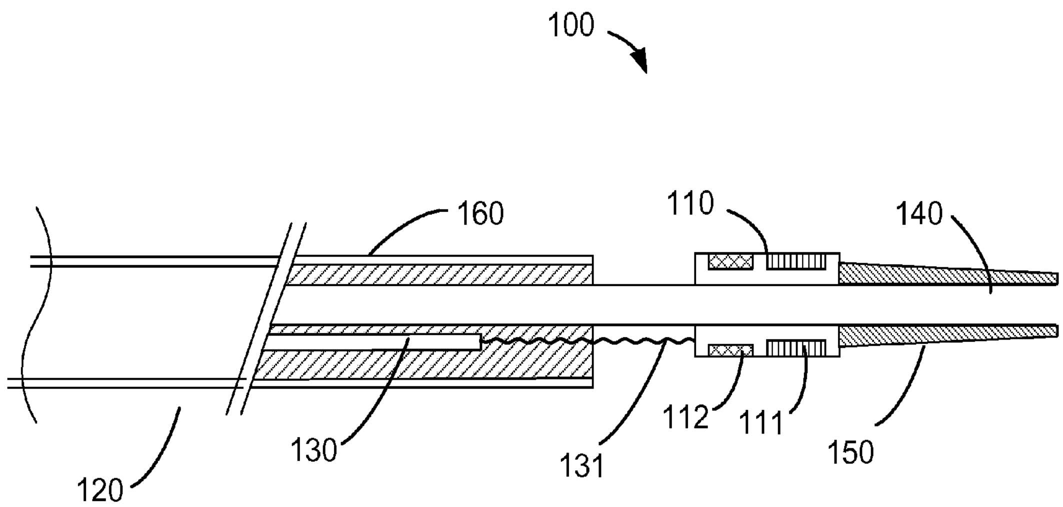
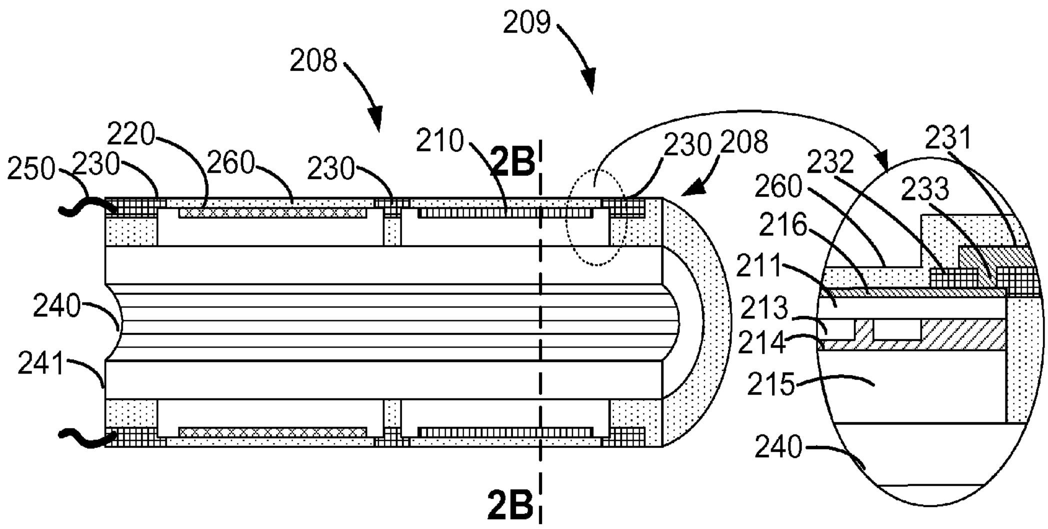


FIG. 1


209
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2B

FIG. 2A

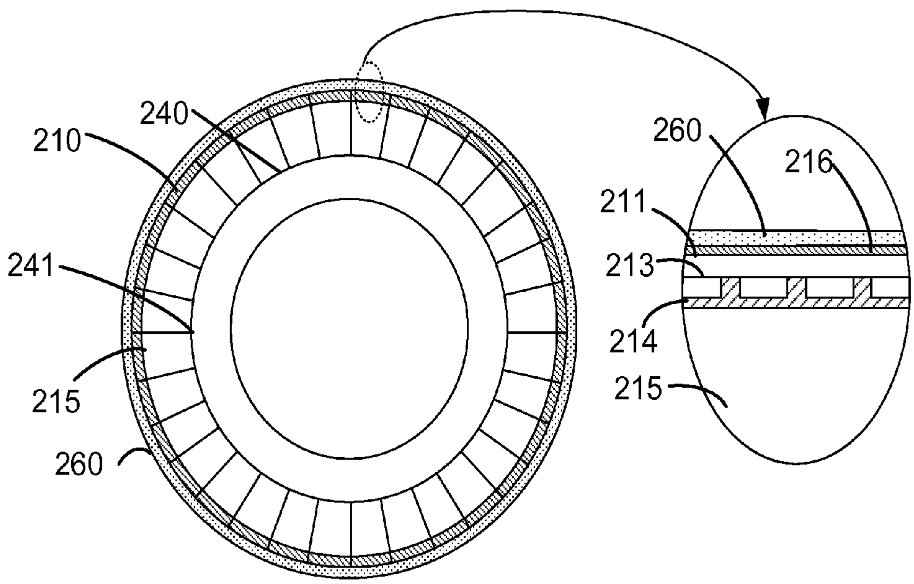
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FIG. 2B

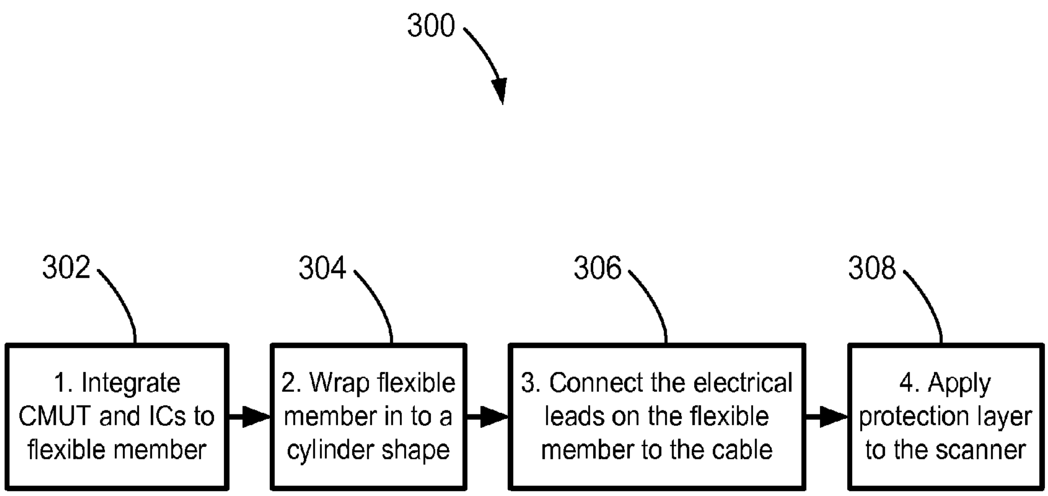
300
302
304
306
308
1. Integrate CMUT and ICs to flexible member
2. Wrap flexible member in to a cylinder shape
3. Connect the electrical leads on the flexible member to the cable
4. Apply protection layer to the scanner

FIG. 3

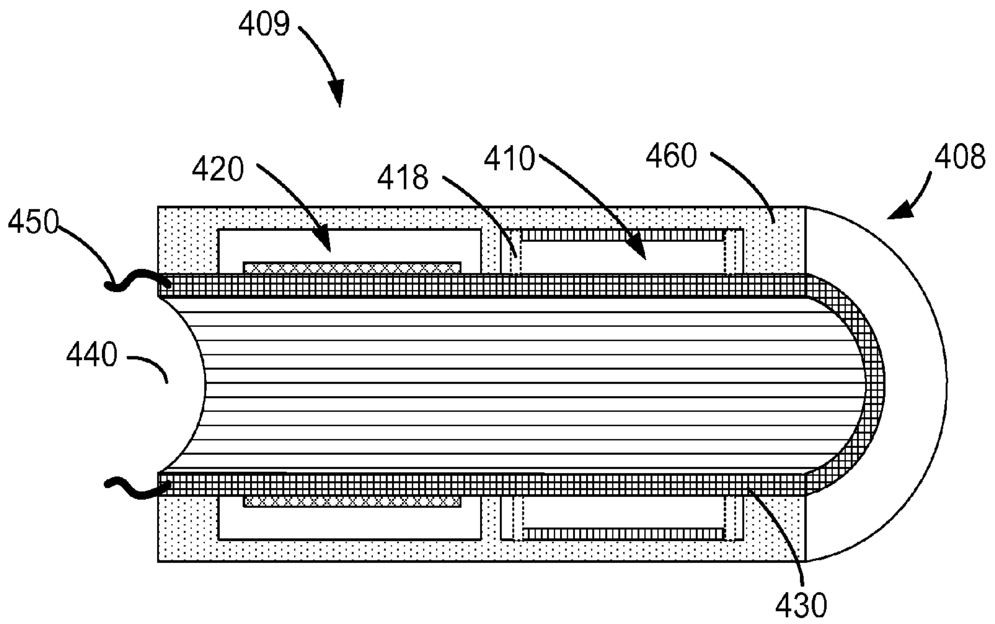
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FIG. 4

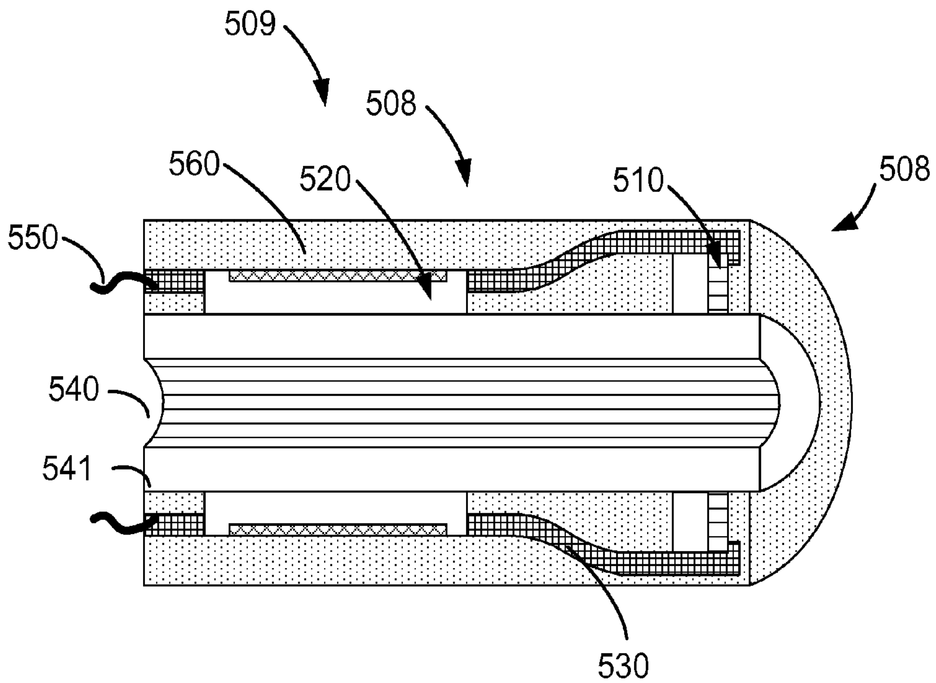
509
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FIG. 5

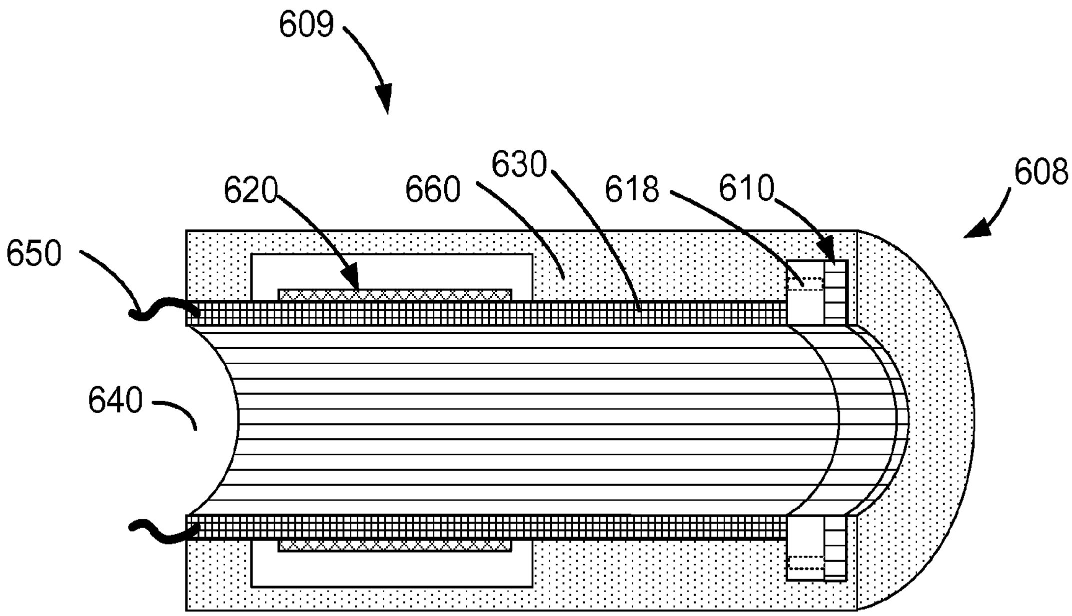


FIG. 6

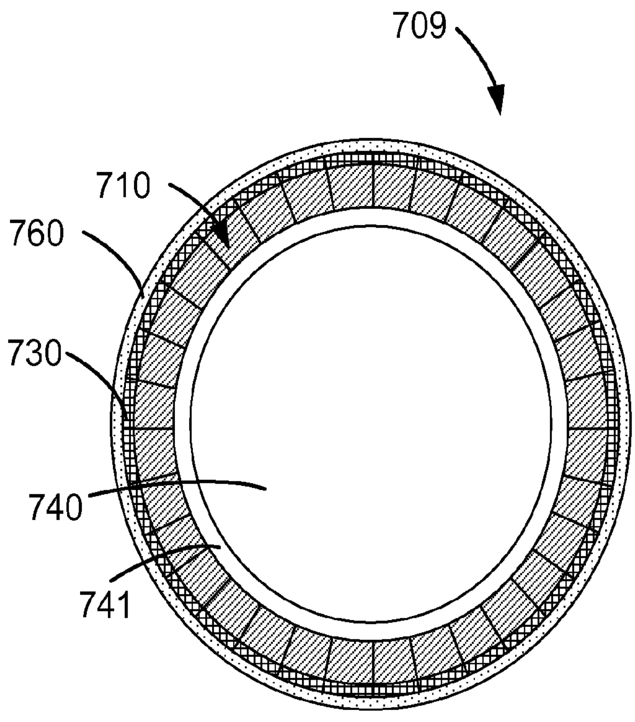


FIG. 7

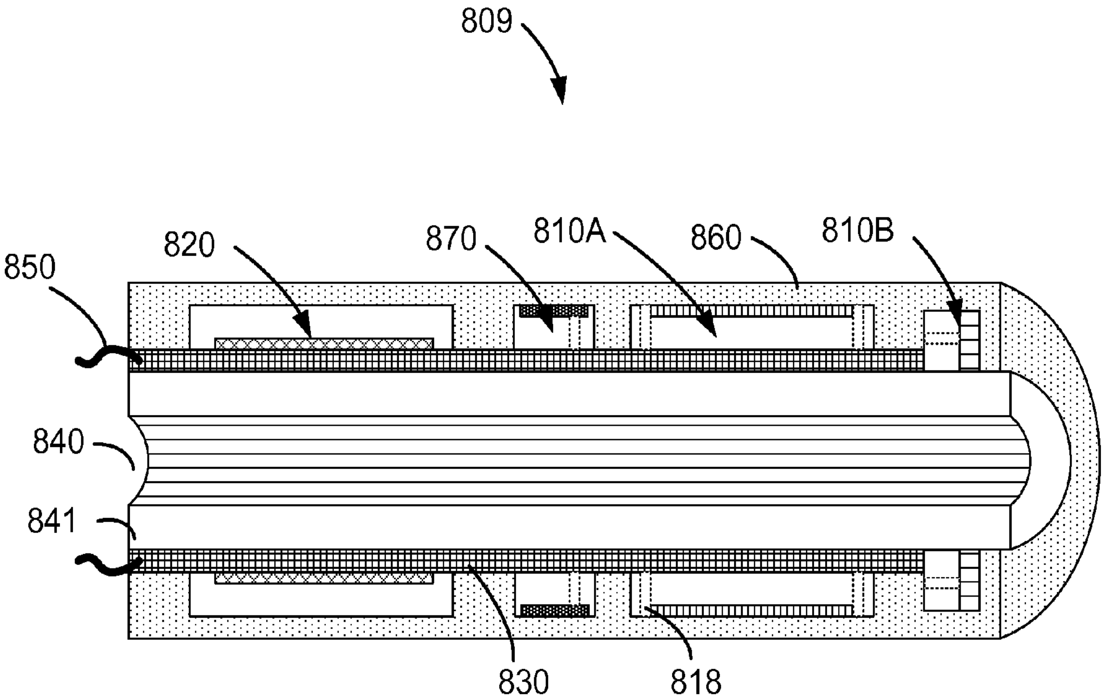


FIG. 8

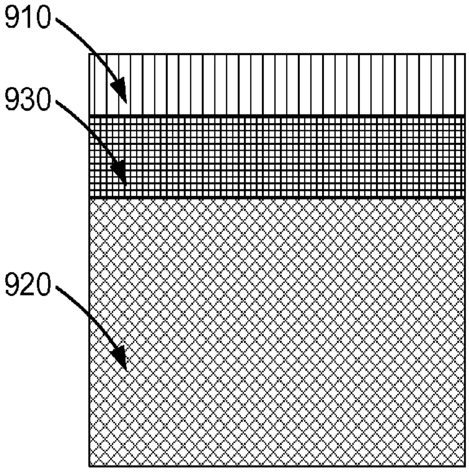


FIG. 9

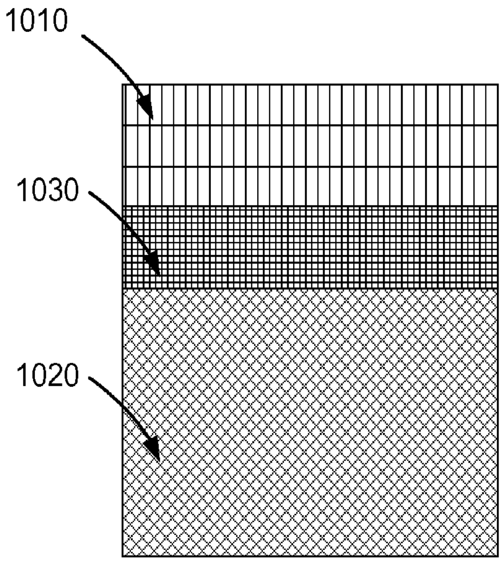


FIG. 10

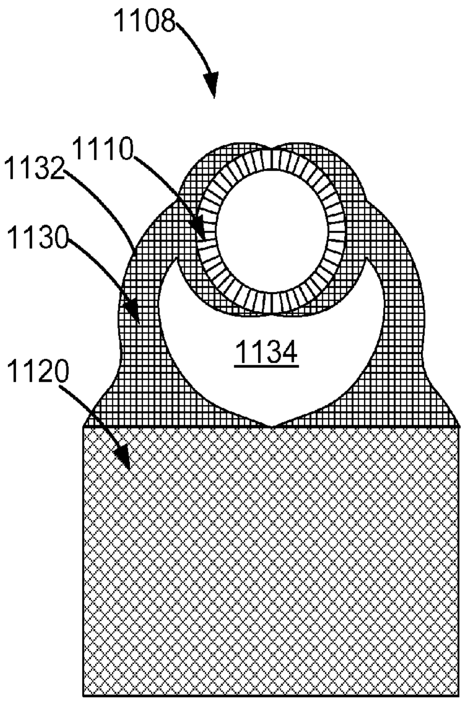


FIG. 11

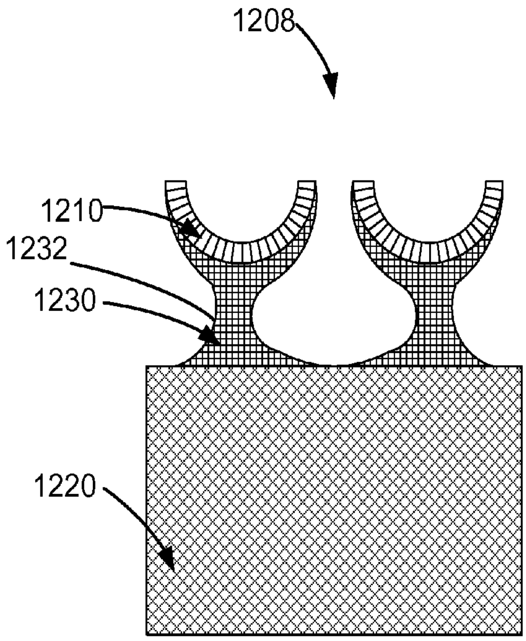


FIG. 12

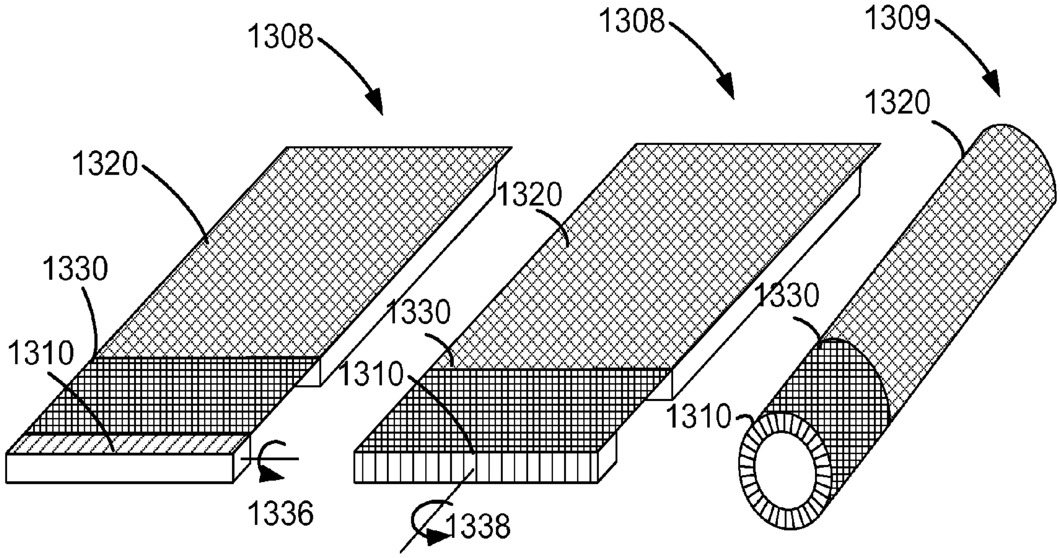


FIG. 13A FIG. 13B FIG. 13C

FIG. 14.1

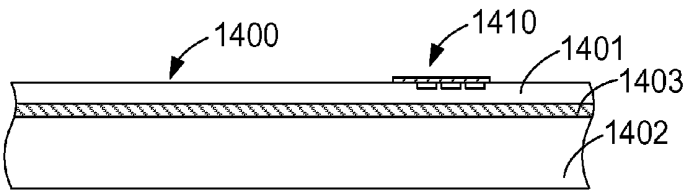


FIG. 14.2

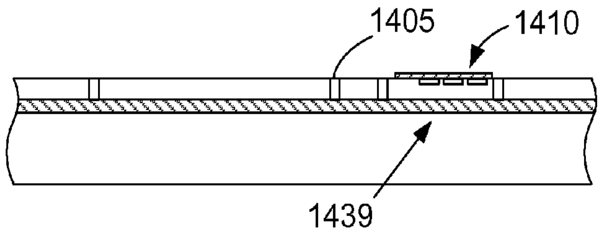


FIG. 14.3

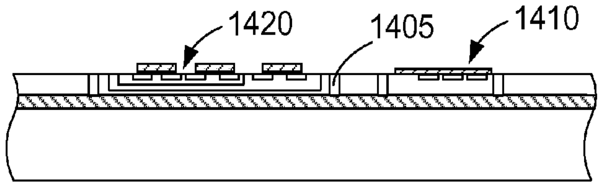


FIG. 14.4

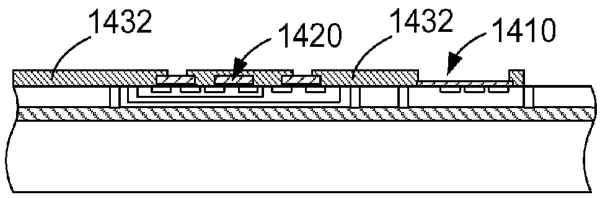


FIG. 14.5

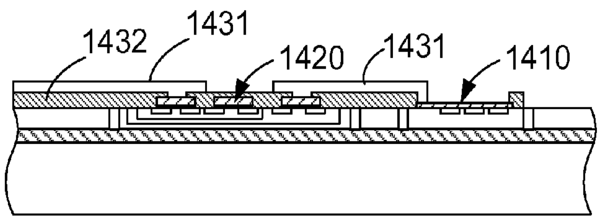


FIG. 14.6

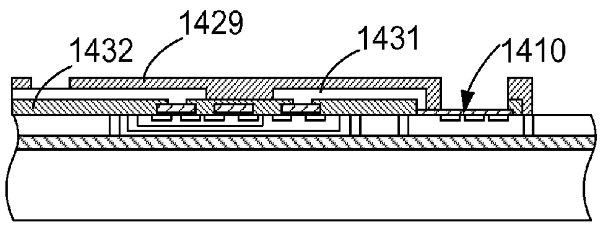
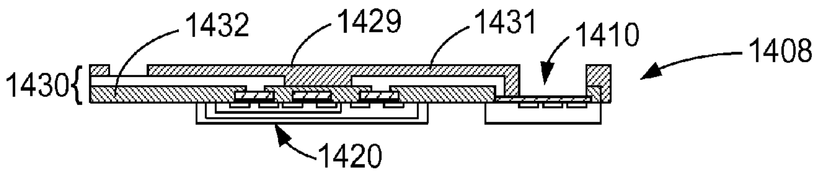


FIG. 14.7



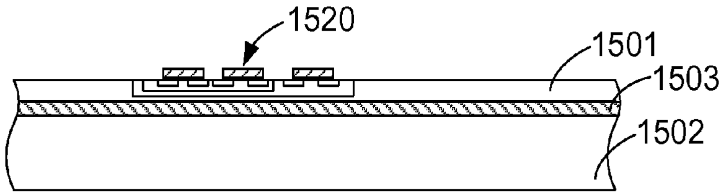


FIG. 15.1

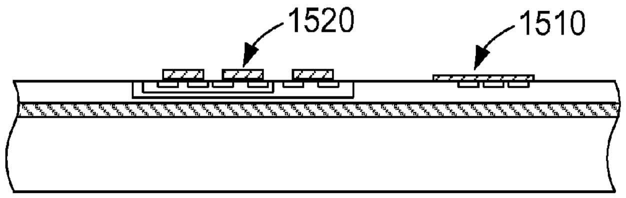


FIG. 15.2

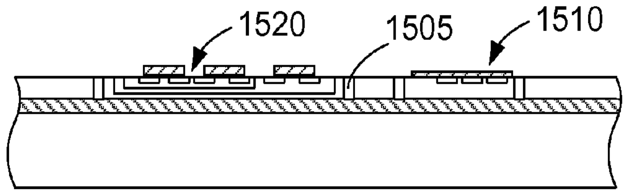


FIG. 15.3

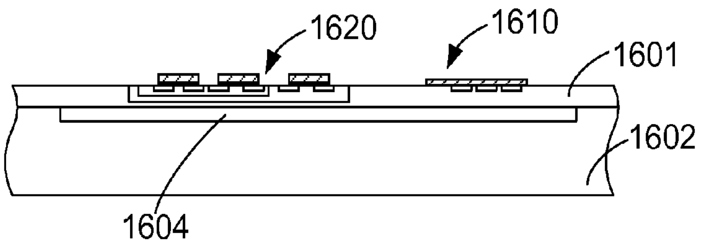


FIG. 16.1

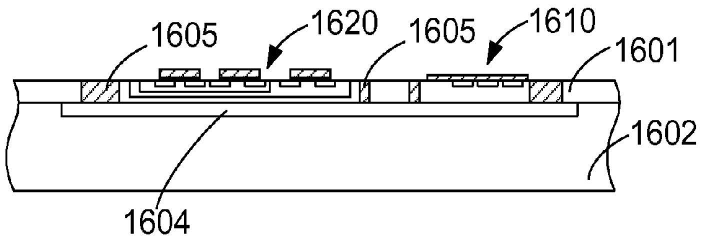


FIG. 16.2

ULTRASOUND SCANNER BUILT WITH CAPACITIVE MICROMACHINED ULTRASONIC TRANSDUCERS (CMUTS)

PRIORITY

[0001] This application claims priority from U.S. Provisional Application Ser. No. 60/992,020, filed Dec. 3, 2007 and U.S. Provisional Application Ser. No. 61/024,843, filed Jan. 30, 2008.

BACKGROUND

[0002] The present application relates to capacitive micromachined ultrasonic transducer (CMUT) scanners and, more particularly to catheters equipped with CMUT based ultrasonic scanners.

[0003] A catheter allows surgical personnel to diagnose and treat conditions deep within a patient's body by navigating the distal end of the catheter to the site where some condition might exist. Then, surgical personnel can operate various sensors, instruments, etc. at the site to perform certain procedures with minimal intrusive effect on the patient. One type of sensor that has found widespread use is the ultrasonic scanner. Ultrasonic scanners generate acoustic waves at frequencies selected for their ability to allow the acoustic waves to penetrate various tissues and other biological structures and return echoes there from. Often, it is desired to select frequencies on the order of 20 MHz or higher. Images of the tissue surrounding the ultrasonic scanner can be derived from these returned echoes. Two types of ultrasonic scanners exist, those which are based on piezoelectric crystals (i.e., a crystal fabricated from a piezoelectric material or a piezoelectric composite material) and those based on capacitive micromachined ultrasonic transducers (CMUTs and embedded spring CMUTS or ESCMUTs).

[0004] CMUTs typically include two spaced apart electrodes with a membrane attached to one of the two electrodes. In operation, an alternating current (AC) signal is used to charge the electrodes to differing voltages. The differential voltage induces movement of the electrode attached to the membrane and hence, the membrane itself. A piezoelectric transducer (PZTs) also applies an AC signal to the crystal therein causing it to vibrate and produce acoustic waves. The echoes returned to the crystal are used to derive images of the surrounding tissue.

[0005] Thus, surgical personnel have found it useful to employ ultrasonic scanner equipped catheters to obtain images of certain tissues (e.g. blood vessels), structures, etc. within human (and animal) patients and to view the effects of therapy thereon. For instance, ultrasonic transducers can provide images which allow medical personnel to determine whether blood is flowing through a particular blood vessel.

[0006] Some catheters include a single ultrasonic transducer situated at, or near, the distal end of the catheter whereas other catheters include arrays of ultrasonic transducers at the distal end of the catheter. These ultrasonic transducer transducers can be arrange along the side of the catheter and can point outward there from. If so they can be referred to as "side looking" transducers. When the catheter only has one side looking transducer the catheter can be rotated to obtain images of the tissue in all directions around the catheter. Otherwise, the catheter can have ultrasonic transducers pointed in all directions around the catheter.

[0007] In other situations, catheters can have ultrasonic transducers arranged at the distal end of the catheter which point in a distal direction from the end of the catheter. These types of ultrasonic transducers can be referred to as "forward looking" transducers. Forward looking transducers can be useful for obtaining images of tissue in front of (i.e. "forward" of) the catheter.

SUMMARY

[0008] Embodiments provide catheters equipped with ultrasonic scanners and methods of manufacturing catheters equipped with ultrasonic scanners. More particularly, a method practiced according to one embodiment includes integrating a flexible electronic device (e.g. an integrated circuit) with a flexible member and integrating a flexible ultrasonic transducer (e.g. a portion of a circular CMUT array) with the flexible member. The integrated flexible electronic device, flexible ultrasonic transducer, and flexible member can form a flexible subassembly which is rolled up to form the ultrasonic scanner.

[0009] In some embodiments, the integration of the flexible electronic device and the flexible ultrasonic transducer with the flexible member occurs at the same time. Furthermore, the integration of the ultrasonic transducer can be performed from the side of ultrasonic transducer which includes its active surface. In the alternative, the integration of the flexible electronic device can occur before (or after) the integration of the flexible ultrasonic transducer. Moreover, the integration of the flexible ultrasonic transducer can include using a semiconductor technique. In some embodiments, the rolled up flexible subassembly forms a lumen which can be coupled to the lumen of a catheter. However, the rolled up flexible subassembly can be attached to a lumen of a catheter instead. In some embodiments, the method includes folding a portion of the flexible member (which hosts the flexible ultrasonic transducer) through an angle of about ninety degrees to form a forward looking ultrasonic transducer. The flexible member of some embodiments can include a pair of arms attached to portions of a circular array of CMUT transducers. As the arms (and the rest of the flexible member) are rolled up, the circular CMUT array can be folded through about ninety degrees to form a ring shaped CMUT array. The ring shaped CMUT array can then be used as a forward looking CMUT array.

[0010] One embodiment of an ultrasonic scanner disclosed herein includes a flexible electronic device (e.g. an integrated circuit), a flexible ultrasonic transducer; and a flexible member with the flexible electronic device and the flexible ultrasonic transducer integrated with the flexible member. The integrated flexible electronic device, the flexible ultrasonic transducer, and the flexible member can form a flexible subassembly which is rolled up to form the ultrasonic scanner. In some embodiments, the rolled up flexible subassembly is a lumen or, instead, can be attached to a lumen of a catheter. The flexible ultrasonic transducer can include a through wafer interconnect and a portion of a circular CMUT array in communication therewith. Moreover, the ultrasonic transducer can be a forward looking, ring shaped CMUT array.

[0011] Accordingly, embodiments provide many advantages over previously available ultrasonic transducer equipped catheters and, more particularly, over PZT equipped catheters. For instance, embodiments provide catheters with ultrasonic scanners which can operate at higher frequencies and with wider bandwidths than heretofore possible. Embodiments also provide catheters with ultrasonic scanners

with smaller form factors than those of previously available ultrasonic transducers. In addition, embodiments provide methods of manufacturing catheters equipped with ultrasonic scanners which are simpler, less costly, and faster than previously available ultrasonic catheter manufacturing methods.

BRIEF DESCRIPTION OF THE FIGURES

[0012] FIG. **1** illustrates a cross sectional view of a catheter of some embodiments.

[0013] FIG. **2** illustrates cross sectional views of an ultrasonic scanner of some embodiments.

[0014] FIG. **3** illustrates a flow chart illustrating a method of manufacturing a catheter of some embodiments.

[0015] FIG. **4** illustrates a cross sectional view of an ultrasonic scanner for a catheter of some embodiments.

[0016] FIG. **5** illustrates a cross sectional view of another ultrasonic scanner for a catheter of some embodiments.

[0017] FIG. **6** illustrates a cross sectional view of another ultrasonic scanner for a catheter of some embodiments.

[0018] FIG. **7** illustrates a cross sectional view of an ultrasonic scanner for a catheter of some embodiments.

[0019] FIG. **8** illustrates a cross sectional view of yet another ultrasonic scanner for a catheter of some embodiments.

[0020] FIG. **9** illustrates a one dimensional CMUT array for a catheter of some embodiments.

[0021] FIG. **10** illustrates a two dimensional CMUT array for a catheter of some embodiments.

[0022] FIG. **11** illustrates a subassembly of a ring shaped CMUT array for a catheter of some embodiments.

[0023] FIG. **12** illustrates a subassembly of a ring shaped CMUT array for a catheter of some embodiments.

[0024] FIG. **13** illustrates a method of manufacturing a ring shaped CMUT array for a catheter of some embodiments.

[0025] FIG. **14** illustrates a method of integrating various components of a CMUT equipped catheter of some embodiments.

[0026] FIG. **15** illustrates another method of integrating various components of a CMUT equipped catheter of some embodiments.

[0027] FIG. **16** illustrates a wafer from which various components of a CMUT equipped catheter can be fabricated.

DETAILED DESCRIPTION

[0028] Various embodiments provide ultrasonic scanners which are positioned at the distal ends of catheters. More particularly, some embodiments provide ultrasonic scanners equipped with side looking and forward looking capacitive micromachined transducer (CMUT) arrays at their distal ends.

[0029] Though piezoelectric transducers (PZTs) can perform some desirable diagnostic functions, it remains difficult to obtain piezoelectric transducers (PZTs) with small form factors. More specifically, due to constraints associated with the materials from which PZTs are manufactured, it remains difficult to design and manufacture catheters with PZTs small enough to fit within many catheters designed to be navigated through various cardiovascular vessels, neurovascular vessels, and other biologic structures. Moreover, PZT materials do not lend themselves well to relatively high frequency regimes. For example, it is difficult to design and manufacture a PZT capable of operation in the region near (and above) 20 MHz which is useful for imaging biological tissues.

[0030] Furthermore, to form cylindrical arrays of PZT (such as the cylindrical arrays desirable for inclusion on various catheters) the individual PZTs must be diced from flat sheets of the transducers. The individual PZTs can then be arranged in a cylindrical array on the catheter. As a result, some of the individual PZTs (or groups thereof) can be damaged or contaminated with kerf or other contaminants during the dicing and assembly operations. Additionally, the dicing operation and the assembly of the individual PZTs on to the catheter can lead to variations in the operational characteristics of the individual PZTs. Thus, previously available PZTs have found use in only certain ultrasound applications. This disclosure provides CMUT based ultrasonic transducers, and catheters equipped with such CMUTs which address at least some of the shortcomings of PZTs. As discussed herein, the ultrasonic transducers and catheters disclosed herein also possess other advantages.

[0031] CMUTs transmit and detect acoustic waves in adjacent media using two plate-like structures arranged to form a capacitor. The plates (or electrodes coupled to the plates) can be repetitively charged to displace one plate relative to the other thereby generating the acoustic waves. Typically, an alternating current (AC) charges the plates. In the alternative, the plates may be charged to a selected voltage (with, for example, a direct current or DC signal) and can be used to sense acoustic waves which impinge on the exposed plate and therefore displace that plate relative to the other plate. The displacement of the exposed plate causes a change in the capacitance of the CMUT. The resulting electric signal generated by the CMUT can be analyzed to generate images of the media surrounding the CMUT. Some CMUT based ultrasonic scanners include switches so that, when the switch is in one position, the switch allows the CMUT to transmit acoustic waves and, when the switch is in the other position, the switch allows the CMUT to detect acoustic waves.

[0032] CMUTs can be fabricated separately or can be fabricated in various types of arrays. For instance, a one dimensional (1-D) array of CMUTs can be fabricated wherein the various CMUTs are formed in a linear array. 2-D CMUT arrays can also be fabricated in which the various CMUTs are formed in various patterns including, for example, rows and columns. The rows and columns can create arrays which are generally square, rectangular, or other shapes. Moreover, individual CMUTs can be operated separately; can be operated in conjunction with other CMUTs; or can be operated in conjunction with all of the CMUTs in a particular array or scanner. For instance, the signals driving the various CMUTs can be timed to operate a number of the CMUTs as a phased array to direct the acoustic energy in a particular direction(s).

[0033] CMUT arrays can be formed to be flexible so that the array can conform to a surface, cavity, etc. with a desired or given shape or curvature. For instance, CMUT arrays can be fitted to conform to the shape of a particular instrument, catheter, or other device. Similarly, the ICs (or other electronic circuits) used to drive the CMUTs (and sense the signals there from) can be formed to be flexible also. Furthermore, the CMUTs and ICs can be integrated with each other and the instrument at the same time using the same techniques or at separate times using the same (or different) techniques as disclosed herein.

[0034] More particularly, the CMUTs and ICs of some embodiments can be integrated with each other and a flexible membrane at the same time using semiconductor or micro electromechanical systems (MEMS) fabrication and packaging techniques (hereinafter "semiconductor" techniques). The flexible membrane, with the CMUTs and ICs on it, can be wrapped onto a catheter (or other device) to form a catheter with a CMUT based ultrasonic scanner. These CMUT based ultrasonic scanners can be forward looking, side looking, or combinations thereof. In some embodiments, other transducers (e.g., pressure, temperature, etc.) can be fabricated and integrated with the CMUTs and ICs on the flexible membrane.

[0035] FIG. **1** illustrates a cross sectional view of a catheter of some embodiments. The catheter **100** includes an ultrasonic scanner **110** which comprises a CMUT transducer **111**, various electronics **112**, a flexible and elongated body **120**, a cable **130**, connection wires **131**, a lumen **140**, a flexible distal tip **150**, and an outer cover **160**. The catheter **100** typically also includes a handle at the proximal end of the elongated body **120**. The handle allows surgical personnel with, or without, navigation aids to steer the distal tip **150** through vessels (e.g. cardiovascular vessels) within a patient's body. The distal tip **150** can be coupled to the distal end of the elongated body **120** and can be flexible enough that it guides the distal end of the elongated body **120** through the vessel without affecting the walls of the vessel.

[0036] In addition, the distal tip **150** can include a smooth lead surface to facilitate the passage of the elongated body **120** through the vessel. Outer cover **160** can also be provided over the elongated body **120** (and other portions) of the catheter **100** to facilitated the passage of the elongated body **120** through the vessel. Once the distal tip **150** reaches a desired site, instruments can be inserted through the elongated body **120** and the distal tip **150** via the lumen **140** (which typically runs through the length of the elongated body). Advantageously, the catheter **100** allows surgical personnel to perform ultrasonic diagnostics at the site and to perform these surgical procedures with minimal discomfort for the patient. Catheter **100** can also include one or more sensors, transducers, instruments, etc. for performing various diagnostic procedures at the desired site.

[0037] The lumen **140** can couple the distal tip **150** to the elongated body **120** of the catheter **100**. The lumen **140** can also provide a structure on which the ultrasonic scanner **110** (with the CMUT transducer **111** and the electronics **112**) can be mounted. Typically, the body of the ultrasonic scanner **110** and the body of distal tip **150** are flush with each other so as to present a smooth overall surface to the walls of the vessel through which catheter **100** might be navigated.

[0038] The CMUT transducer **111** can include one or more individual CMUT elements. The various CMUT elements can be arranged in an array within the CMUT transducer **111**. Moreover, CMUT transducer **111** can be a side looking transducer or a forward looking transducer. In some embodiments, catheter **100** includes both side and forward looking transducers.

[0039] Wires **131** can carry electronic data and control signals between external support electronics and the ultrasonic scanner **110**. In some embodiments, the external support electronics can include a control station computer with software to analyze the signals from the ultrasonic scanner and to generate images of the tissue surrounding the ultrasonic scanner. Cable **130** routes the wires **131** from the proximal end of the elongated body **120** to the distal end of the catheter **100**. At the distal end of the elongated body **120**, the wires **131** can electrically connect to the electronics **112**. Furthermore, interconnects (not shown) can electrically connect the electronics **112** and the CMUT transducer **111**. The wires **131** can provide electrical power to the electronics **112**. In turn, the electronics **112** can power the CMUT transducer **111** and provide a switch or switches arranged to cause the CMUT transducer **111** to switch between transmitting and detecting acoustic waves.

[0040] From the CMUT transducer **111** electronic signals indicative of the detected acoustic waves can travel to the electronics **112** via the interconnects. The electronics can perform certain functions (e.g., filtering, signal conditioning, etc.) on these electronic signals. The electronics **112** can send the electronic signals to external supporting electronics (not shown) via the wires **131**. In some embodiments, the supporting electronics includes a computer which is configured to analyze the electronic signals and derive various images there from. The wires **131** can therefore provide an interface between the electronics **112** (and the CMUT transducer **111**) and the supporting electronics.

[0041] When it is desired for the CMUT transducer **111** to transmit acoustic waves, the electronics apply an AC signal to the CMUT transducer **111** thereby causing it to generate the acoustic waves. Moreover, the electronics **112** can be configured to apply an AC signal to the CMUT transducer **111** which has a frequency on the order of 1-100 MHz. However, the electronics **112** can be configured to drive the CMUT transducer **111** with AC signals having other frequencies as well. In the alternative, when it is desired for the CMUT transducer **111** to detect acoustic waves, the electronics **112** can apply a bias signal or a modulation signal to the CMUT transducer **111** and sense the returned electronic signal resulting from the echoed acoustic waves.

[0042] With reference now to FIG. **2**A, a cross sectional view of a side looking ultrasonic scanner **209** of some embodiments is illustrated. Ultrasonic scanner **209** includes an IC **220**, a flexible member **230**, a lumen **240** or a shaft **241** (herein after the lumen **240**), a pair of wires **250**, and an outer layer **260**. The CMUT array **210**, IC **220**, and the flexible member **230** (hereinafter a flexible subassembly **208**) can be attached to the lumen **240**. The CMUT array **210** and IC **220** can be fabricated separately (or together) using semiconductor techniques and can be mechanically coupled to each other by the flexible member **230**. Flexible member **230** can also be coupled to the end of the CMUT array **210** which is opposite the IC **220** and vice versa. The flexible member **230** can provide electrical connectivity between the wires **250**, the IC **220**, the CMUT array **210**, and other components of the ultrasonic scanner **209** while allowing these components to move relative to each other during assembling.

[0043] The detailed portion of FIG. **2**A illustrates the attachment of the flexible subassembly **208** to the lumen **240**. The detailed portion of FIG. **2**A also illustrates various components of a particular CMUT element of the CMUT array **210**. These components of the CMUT element include a membrane **211**, an insulation layer **214**, a substrate **215**, a top electrode **216**, a conductive layer **231** (of the flexible member **230**), an insulation layer **232** (of the flexible member **230**), and a via **233** (of the flexible member **230**). Various semiconductor and MEMS materials (hereinafter "semiconductor" materials) can be used to fabricate the CMUT. For instance the membrane **211**, insulation layer **214**, substrate **215**, and top electrode **216** can be formed from silicon, doped silicon, metal, oxide, nitride, etc.

[0044] In some embodiments, the CMUT array **210** is a 1 dimensional CMUT array (which includes one row of CMUT elements, see FIG. 9). However, CMUT array 210 can be other types of CMUT arrays. For instance, CMUT array 210 can be a 1.5 dimensional CMUT array, a 1.75 dimensional CMUT array, or a 2 dimensional CMUT array (which includes 2 rows of CMUT elements, see FIG. 10). The CMUT array 210 can be a flexible CMUT array as described in U.S. Provisional Patent Application No. 60/992,020 entitled ENHANCED CAPACITIVE MICROMACHINED ULTRASONIC TRANSDUCERS, filed on Dec. 3, 2007, by Huang which is incorporated herein as if set forth in full. In addition, or in the alternative, CMUT array 210 can include flexible elements between the individual CMUT arrays therein as described in U.S. Provisional Patent Application No. 61/024,843 entitled PACKAGING AND CONNECTING ELECTROSTATIC TRANSDUCER ARRAYS, filed on Jan. 30, 2008, by Huang which is incorporated herein as if set forth in full. Moreover, these types of CMUT arrays can be formed using semiconductor techniques. The IC 220 can be fabricated in a similar manner as described in the foregoing provisional patent applications and can therefore be flexible also. Thus, the subassembly 208 can be flexible enough to conform to various surfaces (including surfaces which exhibit compound curvature) including lumen 240. While the flexible subassembly 108 can be wrapped around objects or rolled into a tube, a portion of a lumen, or a lumen, the flexible subassembly can be formed into other shapes (even those with compound curves). For instance, the flexible subassembly can be rolled into a cylinder, a portion of a lumens, or a lumens. In contrast, it is impracticable to form a flexible PZT based ultrasonic scanner using semiconductor techniques.

[0045] Regarding the flexible member 230, flexible member 230 can include one or more insulation layers 232 and at least one conductive layer 231. These insulation layers 232 and conductive layers 231 can be fabricated using semiconductor techniques and can be fabricated with thicknesses of as little as 1 micrometer. Accordingly, the separation between interconnects within flexible member 230 can be as little as 1 micrometer thereby increasing the interconnect density as compared to previously available ultrasonic scanners (and more particularly, previously available PZT based ultrasonic scanners). Furthermore, if it is desired to increase the density of the interconnects within flexible member 230, additional insulation layers 232 and conductive layers 231 can be formed in flexible member 230. The layers 231 and 232 of the flexible member 230 can be fabricated from materials which are compatible with semiconductor techniques. For instance, the conductive layer 231 can be made of aluminum, gold, etc. and can be formed by electroplating, sputtering, evaporating etc. a metal or other conductive material onto an appropriate substrate. The insulation layer 232 can be made of Parylene, polydimethylsiloxane (PDMS), nitride, polyimide or Kapton, etc.

[0046] With continuing reference to FIG. 2A, the CMUT membrane 211 and substrate 215 can define the transducing cavity 213. The top electrode 216 of the CMUT can be coupled to the membrane 211 and together with the substrate 215 (which can serve as the bottom electrode of the particular CMUT element shown in the detailed portion of FIG. 2A) can cause the displacement of the membrane 211. More particularly, an electric signal can be applied across the top electrode 216 and the substrate 215 using the connectivity provided by the wires 250, the conductive layer 231, and the via 233 to arcuate the CMUT element thereby generating acoustic waves in the surrounding media

[0047] FIG. 2B illustrates a cross sectional view taken along the line 2B-2B of the ultrasonic scanner 209 of FIG. 2A. It will be understood by those skilled in the art that the CMUT elements of the CMUT array 210 can operate satisfactorily without an acoustic matching or backing layers. Moreover, the CMUT array 210 can operate satisfactorily without a filling material between the lumen 240 and the CMUT array 210. Thus, the flexible CMUT array 210 can be wrapped directly on the lumen 240. In some embodiments, the flexible CMUT array 210 can be rolled into a cylindrical shape and can therefore serve as the lumen 240. Thus, a separate lumen 240 need not be included in the ultrasonic scanner 209. In those embodiments in which the rolled up CMUT array 210 serves as the lumen, the CMUT array 210 can be dimensioned to match the diameter of the lumen included in the elongated body 120 (see FIG. 1) of the catheter 100. Thus, the lumen in elongated body and the rolled up CMUT array 210 can be coupled to form a continuous lumen throughout the length of the catheter 100.

[0048] FIG. 3 is a flow chart illustrating a method of manufacturing an ultrasonic scanner. The method 300 can include integrating the CMUT array 210 and the IC 220 with the flexible member 230 at step 302. In some embodiments, the CMUT array 210 and the IC 220 can be integrated with the flexible member 230 at the same time and using the same techniques. However, in some embodiments, the CMUT array 210 and IC 220 can be integrated with the flexible member 230 at differing times using differing techniques. At step 304, the integrated CMUT array 210, IC 220, and flexible member 230 (as a subassembly 208) can be wrapped into a cylindrical shape. Thus, the subassembly 208 can be wrapped around the lumen 240 or can form the lumen 240. In any case, the resulting ultrasonic scanner 209 can be assembled on to the lumen 140 (see FIG. 1) of the catheter 100. The wires 131 of the catheter 100 can be connected to leads on the flexible member 230 at step 306. At step 308 the outer layer 260 can be applied to the ultrasonic scanner 209 to complete the manufacture of the CMUT based ultrasonic transducer 209. The outer layer 260 can be made of, for example, PDMS, Parylene, polyethylene shrink tubing, polyethylene terephthalate (PET) shrink tubing, etc.

[0049] In contrast to the manufacture of a PZT based ultrasonic scanner, method 300 can omit the dicing of PZT a disc on a flex. Method 300 can also omit the creation of acoustic matching and backing layers. Method 300 can also omit the creation of a layer of filling material between the CMUT array 210 and the lumen 240. Moreover, manufacturing steps such as separately integrating the CMUT array 210 and the IC 220 with the flexible member 230 can be combined, thereby yielding additional cost savings and improving quality control. Accordingly, method 300 can be simpler, with fewer steps, than methods of manufacturing PZT based ultrasonic transducers.

[0050] With reference now to FIG. 14 a method of manufacturing CMUT based ultrasonic scanners is illustrated in more detail than the method 300. More specifically, FIG. 14 illustrates a method of forming a flexible subassembly 1408. FIG. 14 illustrates a wafer 1400 with a device layer 1401, a handling wafer 1402, an insulation layer 1403, several trenches 1405, a CMUT array 1410, several ICs 1420, a flexible insulating layer 1429, a flexible member 1430, a conductive layer 1431, and an insulation layer 1432. Wafer 1400 can be a silicon-on-oxide (SOI) wafer used to fabricate the CMUT array 1410, the ICs 1420, or various combinations thereof. Wafer **1400** can also be used to fabricate the flexible member **1430** and to integrate the CMUT array **1410** and the IC **1420** with the flexible member **1430**.

[0051] With reference now to FIG. **14.1**, wafer **1400** can include the device layer **1401**, the handling wafer **1402**, and the insulation layer **1403**. The device layer **1401** can determine the thickness of the CMUT array **1410** and the ICs **1420**. In the alternative to using a SOI wafer for wafer **1400**, a silicon wafer can be ground to the desired thickness and used in lieu of wafer **1400**. In some embodiments, the area of wafer **1400** which will host the ICs **1420** may be protected by a layer of appropriate masking material during certain steps of the method illustrated by FIG. **14**. FIG. **14.1** illustrates that a CMUT array **1410** can be fabricated on wafer **1400** using various semiconductor fabrication techniques.

[0052] As illustrated by FIG. **14.2** various trenches or opening patterns **1405** can be formed in wafer **1400**. Trenches and patterns **1405** should be etched to reach the insulation layer **1403** of the wafer **1400**. Trenches or patterns **1405** can be used to separate various CMUT arrays **1410**, elements of the CMUT array, ICs **1420**, and other components from each other or from the rest of the device layer **1401**. As with the other steps illustrated by FIG. **14**, appropriate semiconductor techniques can be used to form trenches **1405**. Furthermore, FIG. **14.3** illustrates that the ICs **1420** can be fabricated on wafer **1400**. If the area which hosts ICs **1420** had been coated with a protective material, the protective material could be removed before the fabrication of the ICs **1420**.

[0053] In some embodiments, the CMUT array **1410** is usually made of materials which can tolerate higher temperatures than those likely to be encountered during fabrication of the ICs **1420**. Thus, fabricating the ICs **1420** on the wafer **1400** after the CMUT array **1410** can result in a satisfactory subassembly **1408**. Some embodiments allow the CMUT array **1410** to be fabricated on the wafer **1400** after the fabrication of the ICs **1420** as will be discussed with reference to FIG. **15**.

[0054] With continuing reference to FIG. **14**, the steps shown from FIG. **14.4** to FIG. **14.6** are exemplary process steps which can be used to form the flexible member **1430**. In embodiments which employ these steps, the flexible member **1430** has at least one layer of insulation layer and at least one layer of conductive layer. FIG. **14.4** illustrates that a layer of flexible insulating material (e.g. Parylene, polydimethylsiloxane or PDMS, polyimide, nitride, etc.) can be patterned and created on wafer **1400** as the first insulation layer of the flexible member **1430**. Flexible insulating layer **1432** can be created on wafer **1400** in any appropriate manner. For instance, flexible insulating layer **1432** can be spin-coated, evaporated, sputtered, deposited, etc., on to the wafer **1400**. Moreover, the patterning of the flexible insulating layer **1432** can be selected so that the flexible insulating layer **1432** allows access to the electrodes, leads, contacts, etc. associated with the CMUTs **1410** and the ICs **1420**.

[0055] In FIG. **14.5**, the creation of the conductive layer **1431** of the flexible member **1430** on the wafer **1400** is illustrated. The conductive layer **1431** can be patterned and deposited on the wafer **1400** by any appropriate technique and can be performed in a manner to allow the fabrication of interconnections between the CMUT array **1410**, the ICs **1420**, and other components on wafer **1400**. The conductive layer **1431** can be fabricated from aluminum, gold, copper, titanium, etc. or other appropriate materials by (for instance) deposition, evaporation, sputtering, etc. As may be desired to form the flexible **1430** with multiple insulation and conductive layers, additional conductive layers **1431** and insulating layers **1432** can be patterned and created on wafer **1400** to provide interconnects, vias, and associated insulators for the components hosted by wafer **1400**. Where more than one conductive layer **1431** and insulating layer **1432** is formed on wafer **1400**, various devices such as capacitors, inductors, etc. can be formed therein.

[0056] If desired, an outer layer **1429** can be formed on wafer **1400**. The outer layer may be used as a protection layer and treated as an insulation layer of the flexible member **1430**. Usually, but not necessarily, the outer layer is bio-compatible. Outer layer **1429** is illustrated by FIG. **14.6** and can be formed from a flexible insulating material such as Parylene, PMDS, polyimide, nitride, etc. by various techniques. The thickness, patterning, and material of outer layer **1429** can be selected to provide protection for the subassembly **1408** from mechanical abuse, to electrically and thermally isolate the ultrasonic transducer from its environment, and to provide a smooth and relatively friction free surface for the subassembly **1408** to present to the walls of various vessels into which it might be inserted. After this step, in some embodiments, the flexible member **1430** has been formed on the wafer **1400** to connect the IC(s) **1420** and the CMUT **1410** electrically and mechanically.

[0057] FIG. **14.7** illustrates that the flexible subassembly **1408** can be obtained by the removal of the handling wafer **1402**, the insulation layer **1403**, and the rest of device layer **1402**. Thus, the manufacturing method illustrated by FIG. **14** can result in a subassembly **1408** which includes the CMUT array **1410** and the ICs **1420** integrated with each other and with the flexible member **1430**. Thus, the CMUT array **1410** and the ICs **1420** can be fabricated on, and integrated with, the wafer **1400** using the same techniques.

[0058] With reference now to FIG. **15**, another method of fabricating a subassembly **1508** is illustrated. In the method of FIG. **15**, the CMUT array **1510** is fabricated after the ICs **1520** are fabricated. FIG. **15.1** illustrates that the ICs **1520** can be fabricated on the wafer **1500** before the CMUT array **1510**. Then, as illustrated by FIG. **15.2**, the CMUT array **1510** can be fabricated on the wafer **1500**. The techniques and materials used to fabricate the CMUT array **1510** can include techniques and materials selected to not affect the ICs **1520**. For instance, techniques and materials involving temperatures which the ICs **1520** can tolerate can be used to fabricate the CMUT array **1510**. With continuing reference to FIG. **15**, FIG. **15.3** illustrates that various separation trenches or opening patterns **1505** can be formed in the wafer **1500**. The trenches and patterns **1505** can be etched to reach the insulation layer **1503** of the wafer **1500**. Thereafter, manufacturing of the subassembly **1508** can be similar to that of subassembly **1408** as shown in FIGS. **14.4-14.7**. Thus, the CMUT array **1510** can be fabricated on the wafer **1500** after the ICs **1520** are fabricated on the wafer **1500**.

[0059] While FIGS. **14-15** illustrate the CMUT arrays **1410** and **1510** and the ICs **1420** and **1520** being integrated with the flexible member **1430** and **1530** from the active side of the CMUT arrays **1410** and **1510**, it is possible to integrate these components **1410**, **1420**, **1510**, and **1520** with the respective flexible members **1430** and **1530** from the inactive side of the CMUT arrays **1410** and **1510**. If access from the inactive side is desired, then through wafer interconnections can be fabricated to provide interconnectivity for the various components of the subassemblies **1408** and **1508**. If access is desired from the active side, then through wafer interconnection might are not necessary for that purpose since the CMUTs can be readily accessible.

[0060] FIG. **16** illustrates a method of some embodiments in which the insulating layer **1502** of wafer **1500** is replaced with a cavity. More particularly, FIG. **16.1** illustrates that the wafer can be formed with an embedded cavity **1604**, and the IC(s) **1620** and the CMUT(s) **1610** can be fabricated on the substrate **1601** above the embedded cavities **1604**. FIG. **16.2** illustrates that trenches or opening patterns **1605** can be etched through the substrate layer **1601**. Then, in some embodiments, the trenches or opening patterns **1605** may be filled with a material which can be selected to allow for the separation of the CMUTs **1610** and the ICs **1620**. Thereafter, manufacturing of the subassembly **1608** can be similar to that of subassembly **1408** as shown in FIGS. **14.4**-**14.7**. At final step, the flexible subassemblies **1608** can be easily taken out from the wafer **1600** directly from the front side of the wafer **1600**. With regard to the foregoing methods described with reference to FIGS. **14**-**16**, the flexible members **1430**, **1530**, and **1630** can be formed on the inactive side of the CMUT arrays **1410**, **1510**, and **1630**. Through wafer interconnection can also be provided, depending on whether access to the CMUT arrays **1410**, **1510**, and **1610** is desired from the active or inactive sides of the CMUT arrays.

[0061] Moreover, any of the foregoing methods can be used to fabricate the subassemblies **1408**, **1508**, and **1608**. However, other methods can be used to fabricate the subassemblies **1408**, **1508**, and **1608**. For instance, International Patent Application No. ______, entitled CMUT PACKAGING FOR ULTRASOUND SCANNER, filed on Dec. 3, 2008, by Huang, and which is incorporated herein as if set forth in full describes additional methods of fabricating the subassemblies **1408**, **1508**, and **1608**. International Patent Application No. ______, entitled CMUT PACKAGING AND INTERCONNECTION, filed on Dec. 3, 2008, by Huang, and which is incorporated herein as if set forth in full describes additional methods of fabricating the subassemblies **1408**, **1508**, and **1608**.

[0062] As discussed with reference to FIGS. **14**-**16**, the subassembly **208**, which includes the CMUT array **210** (see FIG. **2**), the ICs **220**, and the flexible member **230**, can be created using semiconductor techniques. Additionally, the CMUT array **210** and the IC **220** can be integrated with the flexible member **230** at the same time if desired. Similarly, if desired, multiple subassemblies **208** can be integrated at the same time. Once integrated, subassembly **208** can be wrapped around, and attached to, lumen **240** to create ultrasonic scanner **209**. Thus, relatively simple ultrasonic scanners **209** can be fabricated and assembled at lower cost and with better quality control than previously possible. Moreover, the methods of manufacturing ultrasonic scanners disclosed herein enjoy the economies of scale offered by the semiconductor techniques used therein.

[0063] With reference now to FIGS. **4**-**8** various ultrasonic scanners **409**, **509**, **609**, **709**, and **809** are illustrated. More particularly, FIG. **4** illustrates a cross sectional view of a side looking ultrasonic scanner **409** of some embodiments. The CMUT array **410** and IC **420** of the ultrasonic scanner **409** can be integrated with the flexible member **430** from the inactive side of the CMUT array **410**. Accordingly, ultrasonic scanner **409** can include one or more through wafer interconnections **418**. Through wafer interconnections **418** can provide electrical connectivity to the CMUT elements of the CMUT array **410** from the back side of CMUT substrate. The ICs **420** can be electrically interconnected with the CMUT elements from their inactive surfaces through the flexible member **430**. FIG. **4** also illustrates that the flexible member **430** (with the CMUT array **410** and IC **420** thereon) can be wrapped around the lumen **440**. Otherwise, the manufacture of the ultrasonic scanner **409** of FIG. **4** can be similar to that of the ultrasonic scanner **209** of FIG. **2**.

[0064] Now with reference to FIG. **5**, a cross sectional view of a forward looking ultrasonic scanner of some embodiments is illustrated. Ultrasonic scanner **509** can include a ring-shaped CMT array **510** in lieu of, or in addition to, a side looking CMUT array (such as CMUT array **410**). The ring shaped CMUT array **510** can be positioned at the distal end of the ultrasonic scanner **509** with its active surface pointed in a distal direction. As described in more detail herein, subassembly **508** (including ring shaped CMUT array **510**) can be fabricated as one structure and can be integrated from its active side. In the alternative, ring shaped CMUT array **510** can be fabricate as two or more components and assembled into a ring shaped array. More particularly, as discussed with reference to FIGS. **11** and **12**, the integrated subassembly **508** can be folded inward at a location proximal to the CMUT array **510** to point the elements of the CMUT array **510** in the distal direction as shown.

[0065] FIG. **6** illustrates another embodiment of a forward looking ultrasonic transducer **609**. Ultrasonic transducer **609** includes a ring-shaped CMUT array **610** which was integrated from its inactive side. Accordingly, CMUT array **610** includes through wafer interconnects **618** to electrically connect the CMUT array **610** to the IC **620**. Additionally, as discussed with reference to FIGS. **11** and **12**, the integrated subassembly **608** be folded outward (in contrast to ultrasonic scanner **509** in which the corresponding subassembly **508** is folded inward) at a location proximal to the CMUT array **610** to point the elements of the CMUT array **610** in a distal or forward direction

[0066] A front view of an ultrasonic scanner **709** which is similar to the ultrasonic scanner **509** (see FIG. **5**) is illustrated in FIG. **7**. Due to the inward folding of the CMUT array **710**, the CMUT array **710** is shown being positioned closer to the lumen **740** than the flexible member **730**. Ultrasonic scanner **609** is similar to ultrasonic scanner **509** in this regard except that a portion of the CMUT array **710** can be positioned further from the lumen **740** than the flexible member **730**. However, both ultrasonic scanner **509** and ultrasonic scanner **609** are expected to have similar operating characteristics.

[0067] Referring now to FIG. **8**, a cross sectional view of an ultrasonic scanner of some embodiments is illustrated. In some embodiments the ultrasonic scanner **809** can include both a side looking CMUT array **810**A and a forward looking CMUT array **810**B. Additionally, the ultrasonic scanner **809** can integrate other sensors **870** (such as a pressure sensor, a temperature sensor, etc.) with various CMUT arrays **810** and electronics (e.g. IC **820**) without departing from the scope of the disclosure. Thus, some embodiments provide multifunction ultrasonic scanners **809**.

[0068] With reference now to FIGS. **11**-**13**, various embodiments of subassemblies **1108**, **1208**, and **1308** of CMUT arrays, ICs, and flexible member are illustrated. These subassemblies **1108**, **1208**, and **1308** can be used to form ultrasonic scanners and, more particularly, forward looking ultrasonic scanners. For instance, FIG. **13** illustrates a process of manufacturing a forward looking ultrasonic scanner **1309**.

FIG. **13** illustrates that the subassembly **1308** (including the one-dimensional CMUT array **1310**, the IC **1320**, and the flexible member **1330** integrated in a generally planar configuration) can be used to manufacture a forward looking ultrasonic scanner **1309** with a ring shaped CMUT array **1310**. Moreover, FIG. **13** illustrates that the CMUT array **1310** can be folded through about 90 degrees relative to the plane defined by the subassembly **1308** and as indicated by reference arrow **1336**. The subassembly **1308** can then be rolled into a cylindrical shape as indicated by reference arrow **1338**. Thus, the forward looking ultrasonic scanner **1309** can be formed from the generally planar subassembly **1308**.

[0069] With reference now to FIG. **11**, a subassembly **1108** with a 1 dimensional CMUT array **1110** and which can also be used to form a forward looking ultrasonic scanner with a ring-shaped CMUT array. More particularly, FIG. **11** illustrates that subassembly **1108** can be generally planar and can include the flexible member **1130** with the CMUT array **1110** and the IC **1120** integrated therewith. CMUT array **1110** can be circular and can lie in, or parallel to, a plane defined by the flexible member **1130**. Flexible member **1130** can include one or more arcuate arms **1132** which mechanically couple the CMUT array **1110** and the IC **1120** and provide electrical connectivity between the same components. The CMUT array **1110**, the IC **1120**, and the arms **1132** can define a void **1134** which can allow arms **1132** sufficient freedom of movement so that the arms **1132** can conform to the cylindrical shape of, for example, a lumen. Arms **1132** can be mirror-images of each other as illustrated.

[0070] To form a ring-shaped CMUT array from subassembly **1108**, the subassembly **1108** can be rolled into a cylindrical shape while circular CMUT array **1110** is folded inwardly. Thus, as the subassembly **1108** is rolled into the cylindrical shape, the CMUT array **1110** can be folded through about 90 degrees so that the CMUT elements of the CMUT array **1110** point forward (or in a distal direction). In some embodiments, such as those where the CMUT array **1110** is integrated from the inactive side (and therefore includes through wafer vias), the CMUT array **1110** can be folded outwardly instead of inwardly.

[0071] Note that the arcuate arms **1132** can be shaped and dimensioned so that they lie flat against an appropriately shaped and dimensioned lumen when the subassembly is assembled to the lumen. In the alternative, when the subassembly **1108** forms the shaft or lumen, the arcuate arms **1132** are shaped and dimensioned so that they generally conform to the cylindrical shape of the rolled up subassembly **1108**. In any case, the rolled up subassembly **1108** can be positioned on the distal end of an appropriately shaped lumen. In the alternative, when the subassembly **1108** forms the lumen, the rolled up subassembly **1108** can form the lumen of a catheter.

[0072] With reference now to FIG. **12** another subassembly **1208** is illustrated. More specifically, FIG. **12** illustrates that subassembly **1208** can also include a pair of arms **1232** and a pair of semi-circular CMUT arrays **1210**. Arms **1232** can be generally straight as opposed to the arcuate arms **1132** of FIG. **11**. While FIG. **12** illustrates the CMUT arrays **1210** as each defining a half circle, the CMUT arrays **1210** need not be identical. For instance, one CMUT array **1210** could define a larger portion of a circle with the other CMUT array **1210** define a smaller portion of a circle. In any case, the subassembly can be rolled into a cylindrical shape with the CMUT arrays **1210** being folded over to form a forward looking ultrasonic scanner **1209**.

[0073] CMUT based ultrasonic scanners provide several advantages over PZT based ultrasonic scanners. These advantages arise, in part, from the relatively low acoustic impedance of CMUTs. CMUTs typically have lower acoustic impedances than air, water, tissue, etc. As a result, and unlike PZTs, CMUTs can be used without a layer of material to match the acoustic impedance of the CMUTs with the acoustic impedance of the surrounding media.

[0074] PZTs also transmit acoustic energy (i.e., acoustic waves) from both their front and rear surfaces. As a result of this characteristic, PZTs require a backing layer on their rear surface to absorb the acoustic energy emitted there from. Otherwise the acoustic waves transmitted from the rear of the PZTs could reflect from various structures and interfere with the operation of the PZTs. However, in absorbing the acoustic energy transmitted from the rear of the PZTs, the backing layers generate heat. As a result, PZTs can become warm, or even hot, during operation thereby reducing their desirability for use in certain applications such as applications requiring their use with catheters. Since CMUTs transmit acoustic energy only from there front surfaces, heating due to misdirected acoustic energy is not a concern for CMUT based ultrasonic scanners. Furthermore, the backing layers (and acoustic matching layers discussed previously) complicate the manufacturing of PZT based ultrasonic scanners. In contrast CMUT based ultrasonic scanners can omit these layers and the attendant manufacturing steps.

[0075] Moreover, CMUT based ultrasonic scanners can be produced using semi-conductor manufacturing techniques. Since these semiconductor techniques benefit from decades of investments by various portions of the semiconductor industry, these techniques can provide relatively high levels of uniformity, precision, repeatability, dimensional control, repeatability, etc. in the CMUTs thereby produced. Further still, many of the foregoing semiconductor techniques can be batch processes. As a result, economies of scale associated with these techniques allow for lower per unit costs for CMUT based ultrasonic scanners, particularly when relatively large volumes of ultrasonic scanners may be desired. For instance, since all of the features of the CMUT arrays on a particular wafer can be patterned simultaneously, the fabrication of multiple CMUT arrays introduce no (or little) overhead as compared to the fabrication of a single CMUT array.

[0076] Additionally, since CMUT based ultrasonic scanners can be produced with semiconductor techniques, integrated circuits (ICs) and other semiconductor devices can be integrated with the CMUT arrays with relative ease. Thus, the CMUT arrays and the ICs can be fabricated on the same wafer at the same time using the same techniques. In the alternative, CMUTs and ICs can be integrated into various transducers at different times. Furthermore, CMUTs and ICs can be fabricated from the same, or similar, biocompatible materials.

[0077] In contrast, the fabrication and integration of PZTs with other components (e.g., ICs) using semiconductor techniques is impracticable due to constraints imposed by the PZT materials Moreover, the available PZT related fabrication and integration techniques suffer from several disadvantages including being labor intensive, being expensive, being subject to manufacturing variations, etc. Furthermore, available PZT techniques meet with additional difficulties as the size of the individual PZT devices approaches the small dimensions (e.g., tens of microns) required for relatively high frequency devices. For instance, separation of the individual

PZT devices is dominated by lapping and dicing techniques which lead to device-to-device variability.

[0078] Accordingly, CMUT based ultrasonic scanners enjoy both performance and cost advantages over PZT based ultrasonic scanners. More particularly, since it is typically desirable for ultrasonic scanners to have transducers with both high frequency operating ranges and small physical sizes, CMUT based ultrasonic scanners can have several advantages over PZT based ultrasonic scanners.

[0079] First, CMUT based ultrasonic scanners can be fabricated with better dimensional control than PZT based ultrasonic scanners. More particularly, CMUT based ultrasonic scanners can be fabricated with minimum dimensions less than about 1 micrometer whereas the minimum dimensions of PZT based ultrasonic scanners are greater than about 10 micrometers. Accordingly, CMUT based ultrasonic scanners can be fabricated with correspondingly smaller CMUT element pitches. Secondly, the minimum width and pitch of CMUT based ultrasonic scanner interconnects can be less than about 2-3 micrometers whereas the minimum interconnect width and pitch for PZT based ultrasonic scanners is greater than about 25 micrometers. Thus, CMUT based ultrasonic scanner interconnects can be fabricated at higher densities than PZT based ultrasonic scanner interconnects. Accordingly, CMUT based ultrasound scanners can possess more transducers (for a given scanner size) or can be smaller (for a given number of transducers) than PZT based ultrasonic scanners.

[0080] Moreover, given the improved device size of CMUT based ultrasonic scanners, as compared to PZT based ultrasonic scanners, CMUT based ultrasonic scanners can be created which can operate up to about 100 MHz. In contrast, PZT based ultrasonic scanners are limited to operating regions well below 20 MHz. Furthermore, since the resolution of an ultrasonic transducer depends on its operating frequency, CMUT based ultrasonic scanners can be fabricated with correspondingly improved resolution. For similar reasons, the bandwidth of CMUT based ultrasonic scanners is wider than the bandwidth of PZT based ultrasonic scanners. Accordingly, CMUT based ultrasonic scanners can be applied to more situations than PZT based ultrasonic scanners.

[0081] The simpler design and fabrication of CMUT based ultrasonic scanners (as compared with PZT based ultrasonic transducers) also gives rise to certain advantages. For instance, since the ICs used to support the CMUTs and the CMUTs themselves can be fabricated with the same techniques, fabrication of the CMUTs and ICs, taken together, can be simplified. Additionally, because CMUTs do not require matching or backing layers, the manufacturing steps associated with these layers can also be eliminated. Likewise, steps associated with integrating the CMUTs and the ICs can be eliminated or, if not, simplified.

[0082] The present disclosure is described with reference to specific embodiments thereof, but those skilled in the art will recognize that the present disclosure is not limited thereto. Various features and aspects of the above-described disclosure may be used individually or jointly. Further, the present disclosure can be utilized in any number of environments and applications beyond those described herein without departing from the broader spirit and scope of the specification. We claim all such modifications and variations that fall within the scope and spirit of the present disclosure. The specification and drawings are, accordingly, to be regarded as illustrative rather than restrictive.

What is claimed is:

1. A method of manufacturing a catheter-based medical device comprising:

integrating an electrical circuit with a flexible member;

integrating an ultrasonic transducer with the flexible member, the integrated electrical circuit, the ultrasonic transducer, and the flexible member being a flexible subassembly;

shaping the flexible subassembly to be the ultrasonic scanner; and

attaching the ultrasonic scanner to the catheter.

2. The method of claim **1** wherein the ultrasonic transducer is flexible.

3. The method of claim **1** wherein the electronic device is flexible.

4. The method of claim **1** further comprising integrating the electronic device and the ultrasonic transducer on a device layer of a substrate before integrating the electronic device and the ultrasonic transducer with the flexible member.

5. The method of claim **4** further comprising forming a least a patterned opening through a device layer of a substrate.

6. The method of claim **5** further comprising forming the device layer with at least one embedded cavity.

7. The method of claim **4** further comprising forming the device layer on a SOI wafer.

8. The method of claim **1** further comprising integrating the electronic device and the ultrasonic transducer with the flexible member at the same time.

9. The method of claim **1** wherein the integrating the ultrasonic transducer includes using a semiconductor technique.

10. The method of claim **1** wherein the shaped flexible member defines at least a portion of a lumen.

11. The method of claim **1** wherein the integrating of the flexible transducer is from the side of the ultrasonic transducer which includes an active surface of the flexible ultrasonic transducer.

12. The method of claim **1** further comprising attaching the shaped flexible member to a lumen.

13. The method of claim **1** wherein the flexible ultrasonic transducer includes at least one capacitive micromachined ultrasonic transducer (CMUT).

14. The method of claim **1** further comprising folding a portion of the flexible member which hosts the flexible ultrasonic transducer wherein the folded portion of the flexible member and the flexible ultrasonic transducer form a forward looking ultrasonic transducer.

15. The method of claim **1** wherein the flexible ultrasonic transducer includes at least a portion of a circular CMUT array.

16. The method of claim **1** wherein the flexible member includes a pair of arms.

17. A catheter-based medical device comprising:

an electronic circuit;

an ultrasonic transducer;

a flexible member with the electronic circuit and the ultrasonic transducer integrated there with, the integrated electronic circuit, the ultrasonic transducer, and the flexible member being a flexible subassembly, the flexible subassembly being shaped to be the ultrasonic scanner; and

a lumen to which the ultrasonic scanner is attached.

18. The catheter-based medical device of claim **17** wherein the ultrasound transducer is a flexible ultrasound transducer.

19. The catheter-based medical device of claim **17** wherein the shaped flexible subassembly defines a portion of a lumen.

20. The catheter-based medical device of claim **17** wherein the flexible ultrasonic transducer includes a through wafer interconnect.

21. The catheter-based medical device of claim **17** wherein the ultrasonic transducer includes at least one CMUT element.

22. The catheter-based medical device of claim **17** wherein the ultrasonic transducer is a CMUT array including at least two CMUT elements.

23. The catheter-based medical device of claim **17** further comprising one of a temperature sensor or pressure sensor integrated with the flexible member.

24. The catheter-based medical device of claim **17** wherein the ultrasonic transducer includes at least a portion of a circular CMUT array.

25. The catheter-based medical device of claim **17** wherein the ultrasonic transducer is a forward looking ultrasonic transducer.

26. A catheter-based medical device comprising:

an integrated circuit;

a capacitive micromachined ultrasonic transducer (CMUT); and

a flexible member with the integrated circuit and the CMUT integrated there with, the integrated circuit, the CMUT, and the flexible member being a flexible subassembly, the flexible subassembly being shaped to function as an ultrasonic scanner and at least a portion of a lumen, the CMUT being positioned on the distal end of the ultrasonic scanner and being a forward looking ring shaped ultrasonic transducer.

27. A method of fabricating a catheter-based medical device comprising:

fabricating the semiconductor device on a substrate which defines a separation layer adjacent to the semiconductor device;

separating the semiconductor device from the substrate by forming a pattern of openings in the substrate, around the semiconductor device; and to a depth sufficient to reach the separation layer;

integrating an electrical circuit with a flexible member;

integrating an ultrasonic transducer with the flexible member, the integrated electrical circuit, the ultrasonic transducer, and the flexible member being a flexible subassembly, wherein the semiconductor device includes at least one of the electrical circuit or the ultrasonic transducer;

shaping the flexible subassembly to be an ultrasonic scanner; and

attaching the ultrasonic scanner to the catheter.

28. The method of claim **27** wherein the semiconductor device is selected from the group consisting of a CMUT element, a CMUT array, an integrated circuit (IC), or a combination thereof.

29. The method of claim **27** wherein the separation layer defines an embedded cavity.

* * * * *

专利名称(译)	超声波扫描仪采用电容式微机械超声换能器（CMUTS）制造		
公开(公告)号	US20100262014A1	公开(公告)日	2010-10-14
申请号	US12/745758	申请日	2008-12-03
[标]申请(专利权)人(译)	黄永立		
申请(专利权)人(译)	黄永利		
当前申请(专利权)人(译)	KOLO TECHNOLOGIES，INC. Achieva的医疗器械（上海）有限公司.		
[标]发明人	HUANG YONGLI		
发明人	HUANG, YONGLI		
IPC分类号	A61B8/00 H04R31/00		
CPC分类号	A61B8/12 A61B8/4483 Y10T29/49005 B06B1/0292 A61B8/445 A61B8/4488 B06B1/0651 B06B3/00 H04R31/00		
优先权	60/992020 2007-12-03 US 61/024843 2008-01-30 US		
外部链接	Espacenet USPTO		

摘要(译)

超声波扫描仪和制造超声波扫描仪的方法。方法的一个实施例包括将柔性电子设备（例如IC）和柔性超声换能器（例如圆形CMUT阵列的一部分）与柔性构件集成。 IC，换能器和柔性构件可以形成柔性子组件，其被卷起以形成超声扫描仪。 IC和传感器的集成可以同时进行。在替代方案中，电子设备的集成可以在换能器的集成之前发生。此外，换能器的集成可包括使用半导体技术。此外，卷起的子组件可以形成内腔或者可以附接到内腔。该方法可以包括折叠柔性子组件的一部分以形成前视换能器。一些子组件的柔性构件可包括一对臂。