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

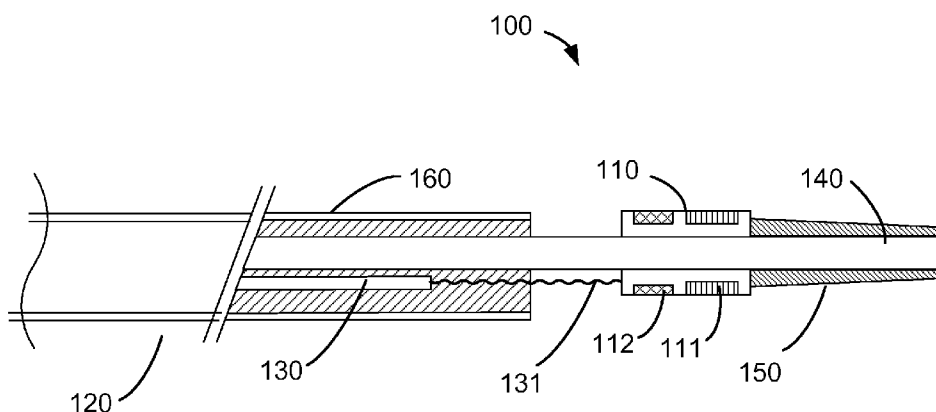


FIG. 1

(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.

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

PRIORITY

[0001] This application claims priority from United States Provisional Applications
5 Serial No. 60/992,020, filed December 3, 2007 and United States Provisional Applications
Serial No. 61/024,843, filed January 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
10 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
15 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 20MHz or higher. Images of the tissue
surrounding the ultrasonic scanner can be derived from these returned echoes. Two types of
20 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 arranged 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.

[00010] 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.

[00011] 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

[00012] Fig. 1 illustrates a cross sectional view of a catheter of some embodiments.

5 [00013] Fig. 2 illustrates cross sectional views of an ultrasonic scanner of some embodiments.

[00014] Fig. 3 illustrates a flow chart illustrating a method of manufacturing a catheter of some embodiments.

10 [00015] Fig. 4 illustrates a cross sectional view of an ultrasonic scanner for a catheter of some embodiments.

[00016] Fig. 5 illustrates a cross sectional view of another ultrasonic scanner for a catheter of some embodiments.

[00017] Fig. 6 illustrates a cross sectional view of another ultrasonic scanner for a catheter of some embodiments.

15 [00018] Fig. 7 illustrates a cross sectional view of an ultrasonic scanner for a catheter of some embodiments.

[00019] Fig. 8 illustrates a cross sectional view of yet another ultrasonic scanner for a catheter of some embodiments.

20 [00020] Fig. 9 illustrates a one dimensional CMUT array for a catheter of some embodiments.

[00021] Fig. 10 illustrates a two dimensional CMUT array for a catheter of some embodiments.

[00022] Fig. 11 illustrates a subassembly of a ring shaped CMUT array for a catheter of some embodiments.

[00023] Fig. 12 illustrates a subassembly of a ring shaped CMUT array for a catheter of some embodiments.

[00024] Fig. 13 illustrates a method of manufacturing a ring shaped CMUT array for a catheter of some embodiments.

5 [00025] Fig. 14 illustrates a method of integrating various components of a CMUT equipped catheter of some embodiments.

[00026] Fig. 15 illustrates another method of integrating various components of a CMUT equipped catheter of some embodiments.

[00027] Fig. 16 illustrates a wafer from which various components of a CMUT
10 equipped catheter can be fabricated.

DETAILED DESCRIPTION

[00028] 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.

[00029] 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) 20MHz which is useful for imaging biological tissues.

[00030] 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.

[00031] 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.

[00032] 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).

[00033] 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
5 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.

10 [00034] 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
15 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.

[00035] 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
20 111, 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.

5 [00036] 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
10 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.

15 [00037] 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
20 might be navigated.

 [00038] 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.

[00039] 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.

[00040] 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.

[00041] 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 1-100MHz. 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.

[00042] With reference now to Fig. 2A, 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.

[00043] The detailed portion of Fig. 2A illustrates the attachment of the flexible subassembly 208 to the lumen 240. The detailed portion of Fig. 2A 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.

[00044] 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 December, 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 January 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.

5 **[00045]** 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
10 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
15 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.

20 **[00046]** 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

5 [00047] 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
10 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
15 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.

 [00048] 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
20 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 5 131 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.

10 [00049] 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 15 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.

[00050] 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. 20 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.

5 **[00051]** 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
10 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.

[00052] 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
15 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
20 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.

[00053] 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.

5 **[00054]** 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,
10 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
15 access to the electrodes, leads, contacts, etc. associated with the CMUTs 1410 and the ICs 1420.

[00055] 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
20 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
5 such as capacitors, inductors, etc. can be formed therein.

[00056] 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
10 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.
15 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.

[00057] 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
20 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.

[00058] 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
5 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
10 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.

[00059] While Figs. 14-15 illustrate the CMUT arrays 1410 and 1510 and the ICs
15 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
20 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.

[00060] 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.

5 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
10 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 1610. Through wafer interconnection can also be provided, depending on whether access to the CMUT arrays 1410, 1510, and 1610 is desired from the
15 active or inactive sides of the CMUT arrays.

[00061] 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
20 December 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 December 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.

[00062] 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.

[00063] 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.

[00064] 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.

[00065] 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

[00066] 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 5 609 are expected to have similar operating characteristics.

[00067] 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 810A and a forward looking CMUT array 810B. Additionally, the ultrasonic scanner 809 can integrate other sensors 870 (such as a pressure 10 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.

[00068] 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 15 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. Figure 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 20 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.

[00069] 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
5 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
10 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.

[00070] To form a ring-shaped CMUT array from subassembly 1108, the
15 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
20 through wafer vias), the CMUT array 1110 can be folded outwardly instead of inwardly.

[00071] 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
5 can form the lumen of a catheter.

[00072] 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
10 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.

[00073] 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
15 20 media.

[00074] 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 their 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.

[00075] Moreover, CMUT based ultrasonic scanners can be produced using semiconductor 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.

[00076] 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.

[00077] 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.

[00078] 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.

[00079] 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.

10 [00080] 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 20MHz. Furthermore, since the resolution of an ultrasonic transducer depends on its operating frequency, CMUT based
15 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.

[00081] The simpler design and fabrication of CMUT based ultrasonic scanners (as
20 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.

[00082] 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
5 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
10 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.

CLAIMS

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.

1/10

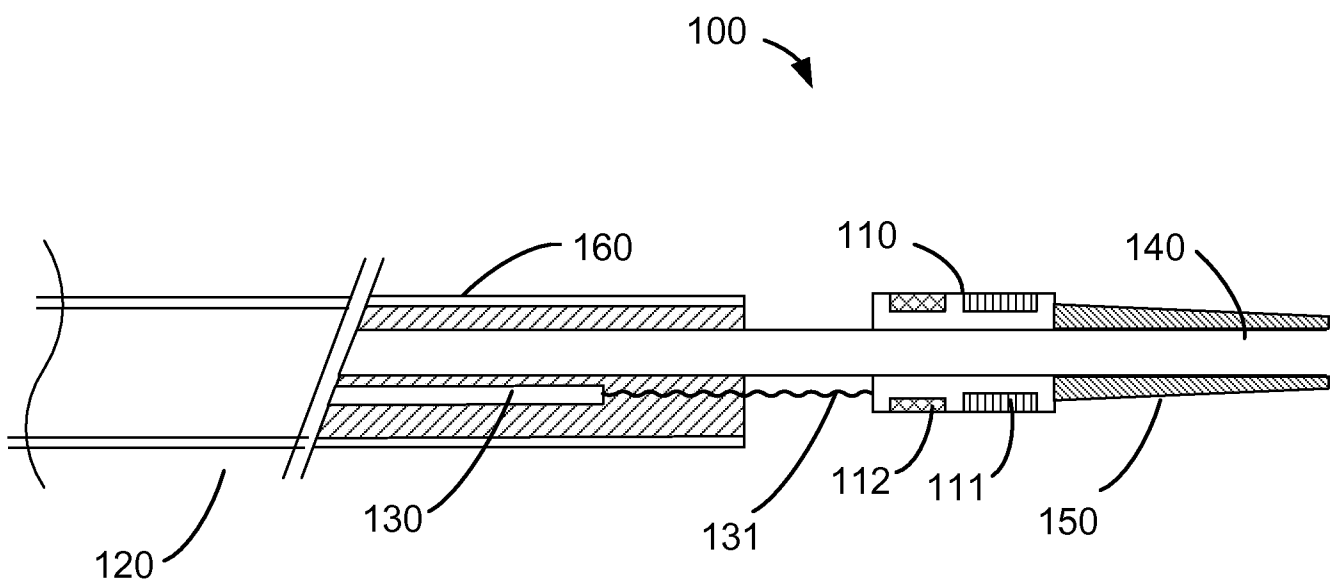


FIG. 1

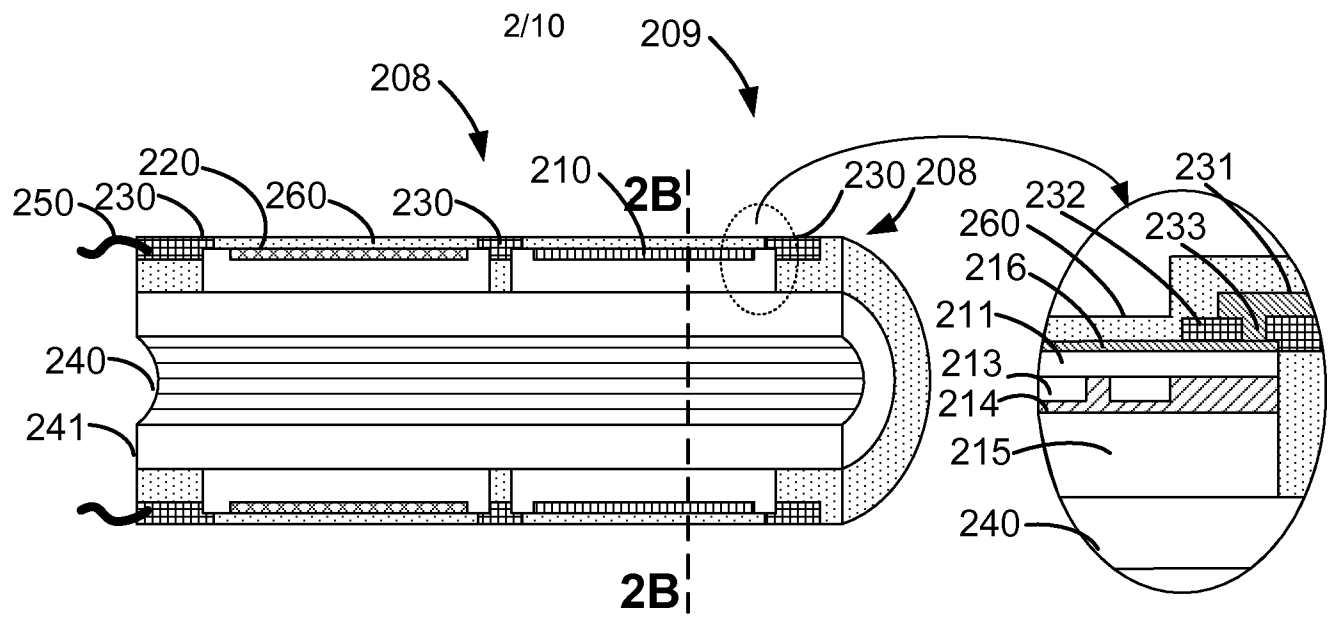


FIG. 2A

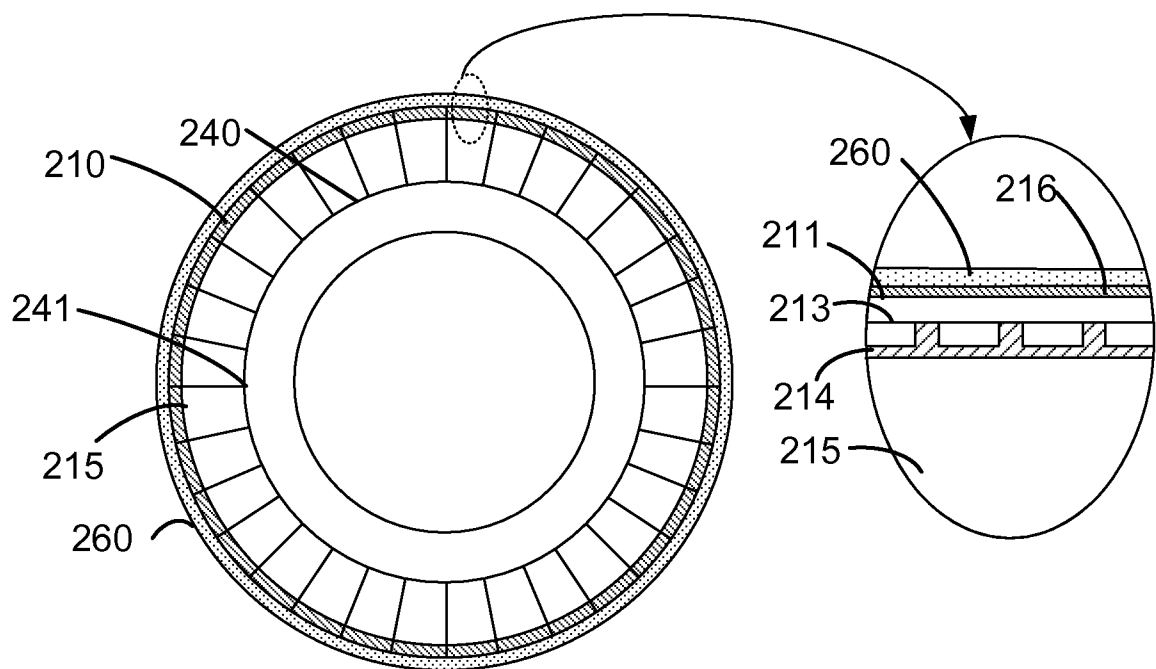
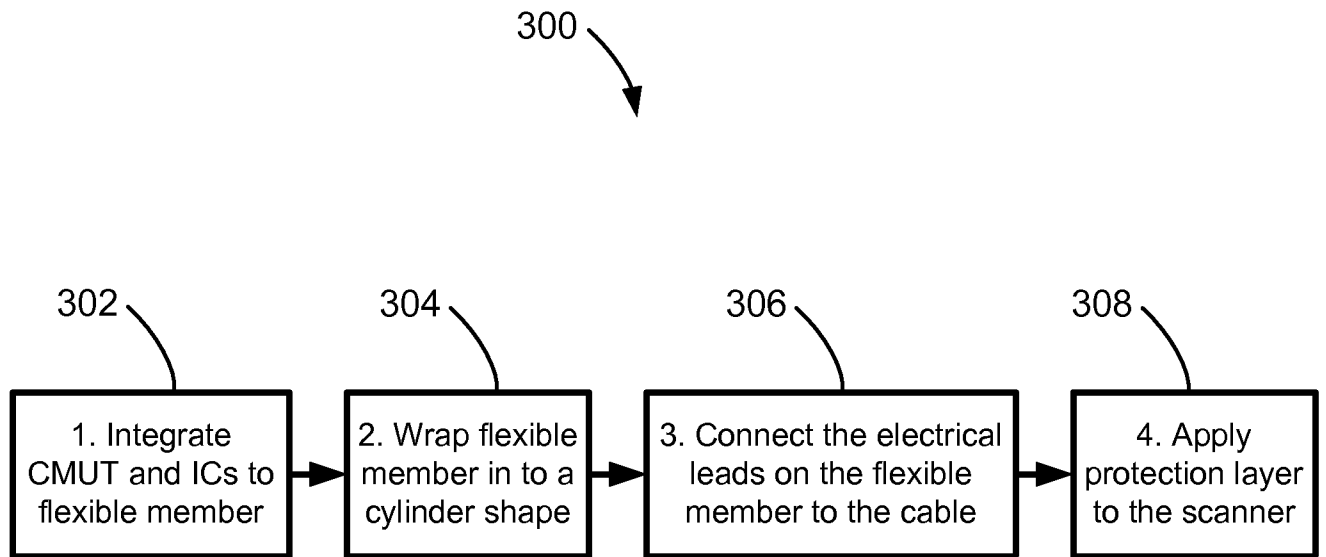


FIG. 2B

3/10

**FIG. 3**

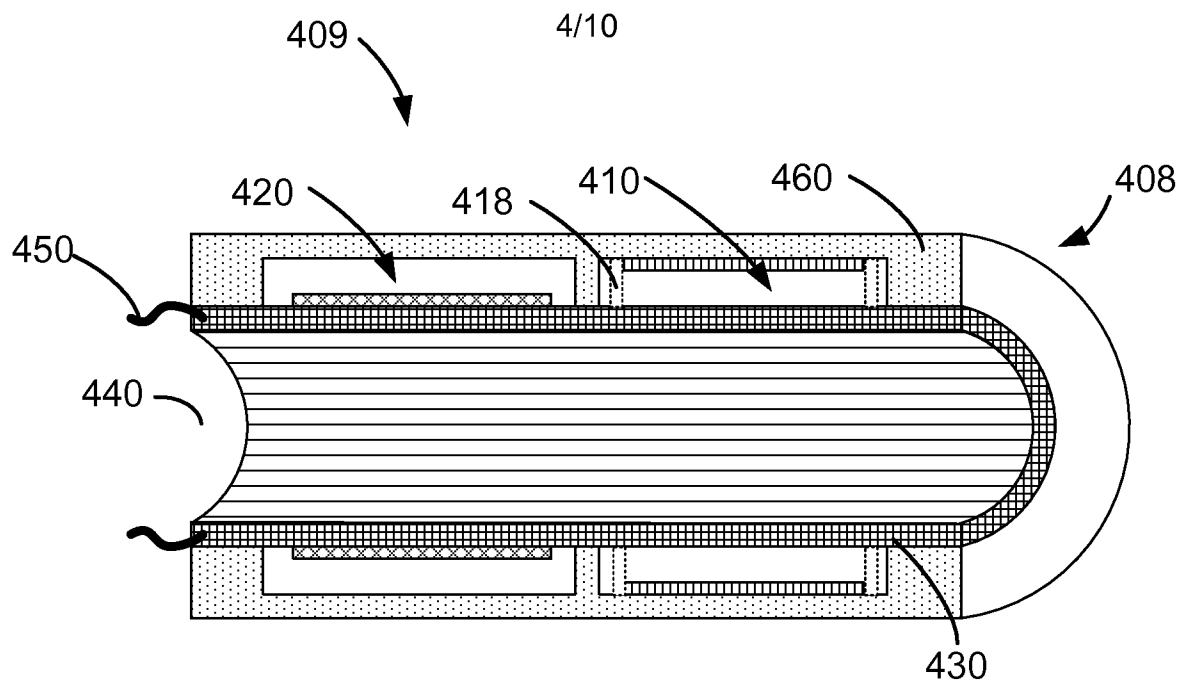


FIG. 4

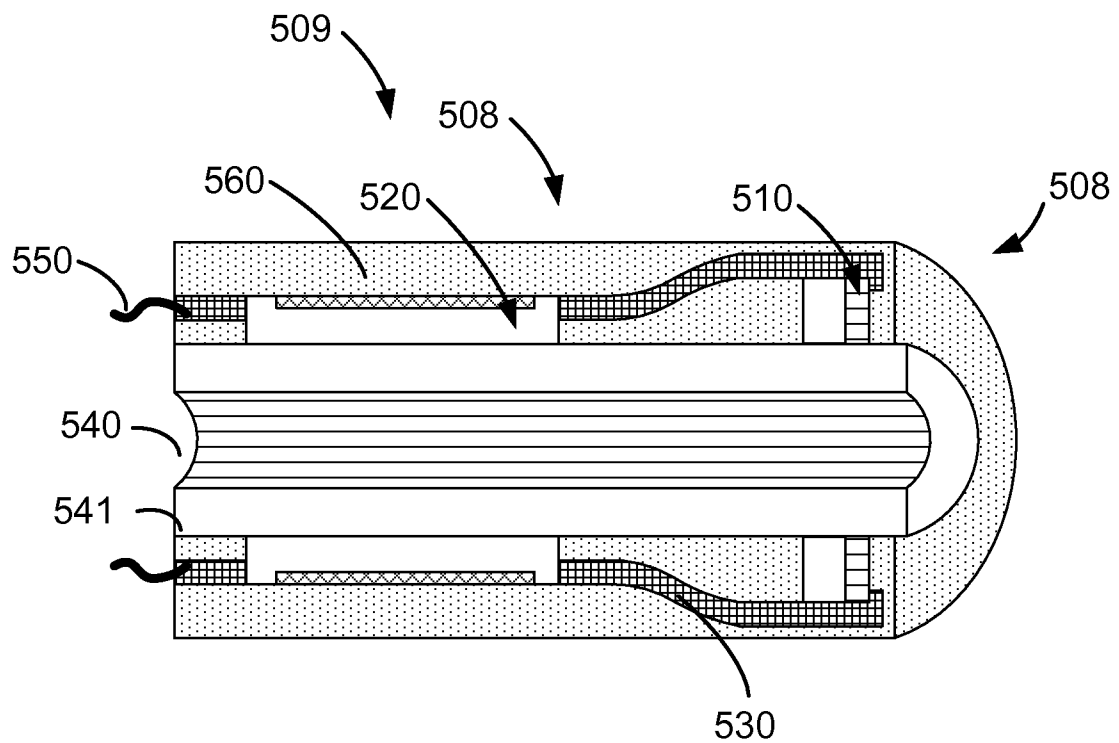


FIG. 5

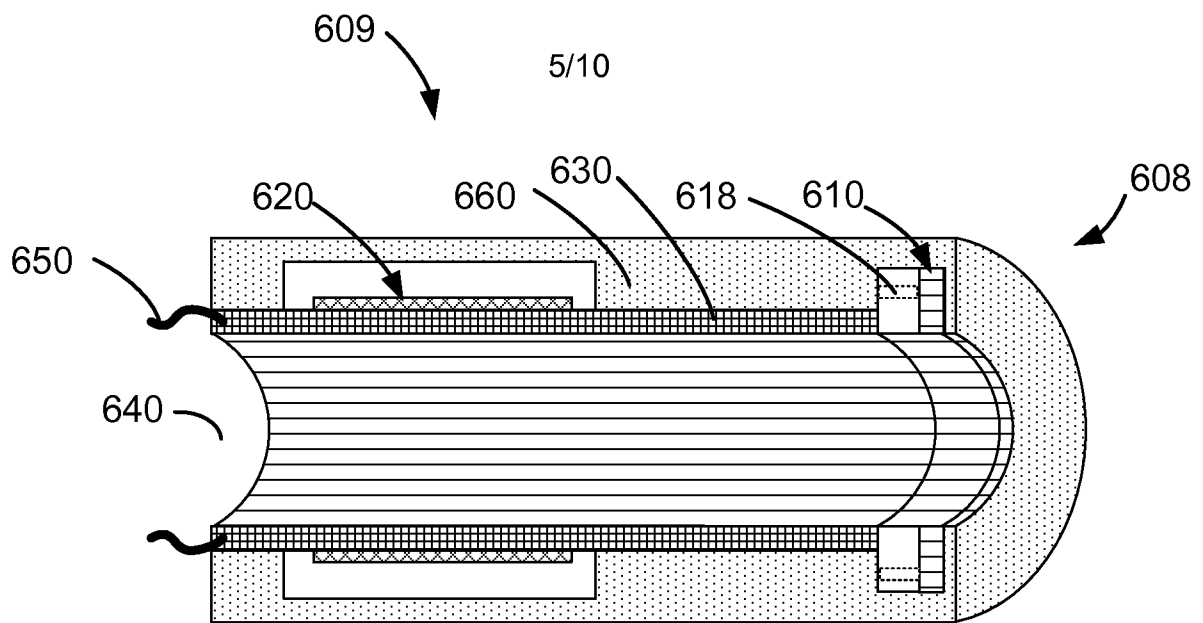


FIG. 6

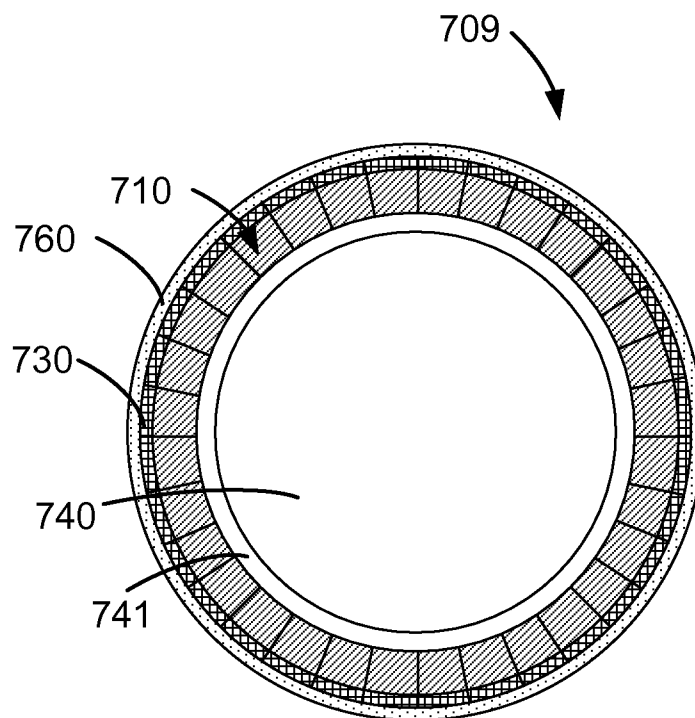


FIG. 7

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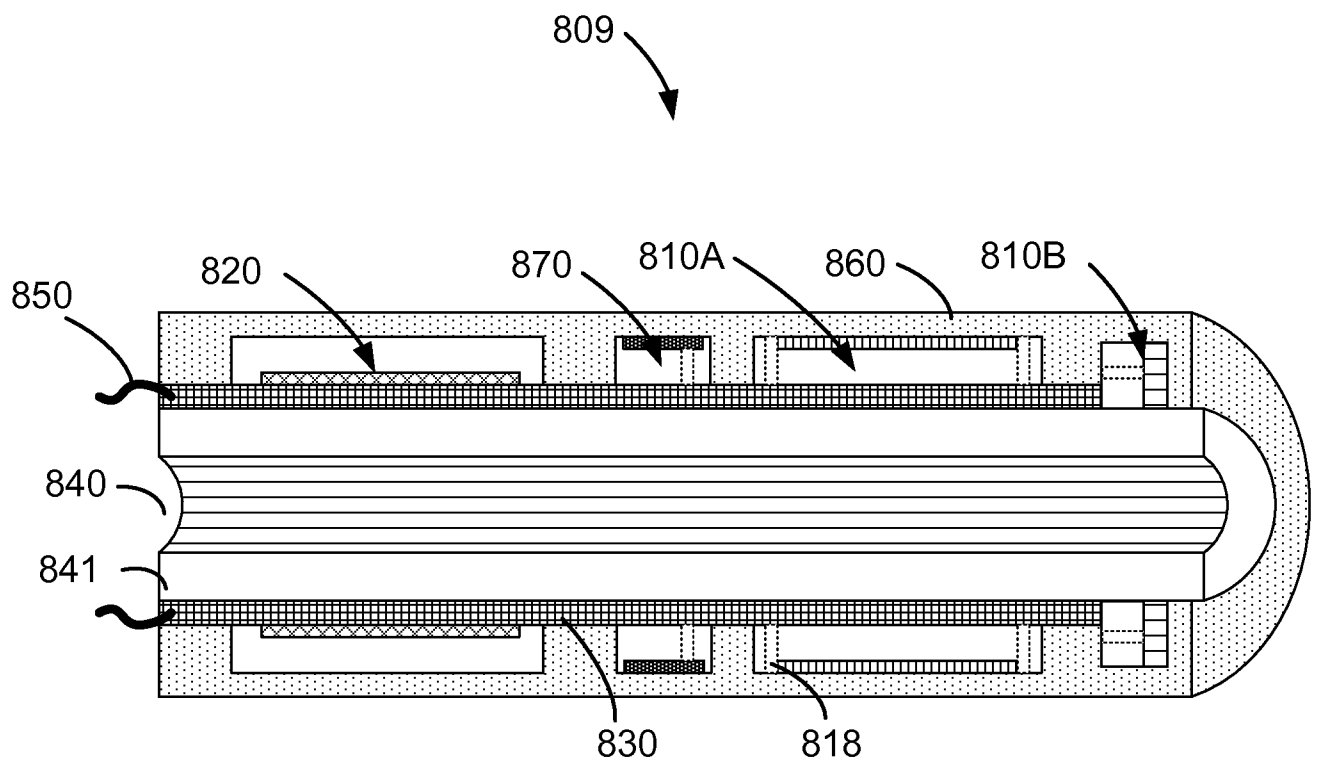


FIG. 8

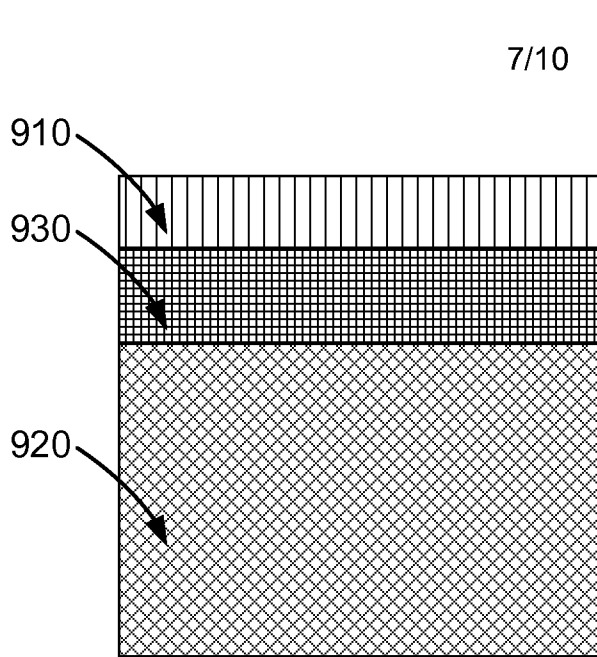


FIG. 9

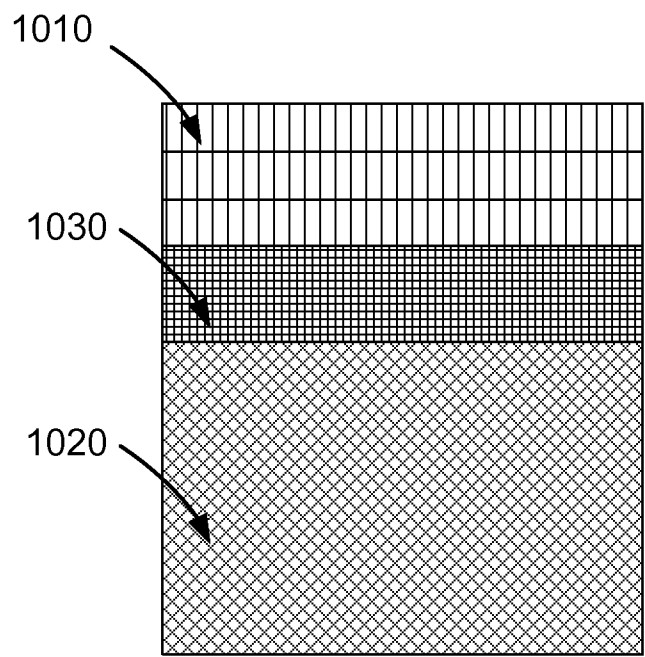


FIG. 10

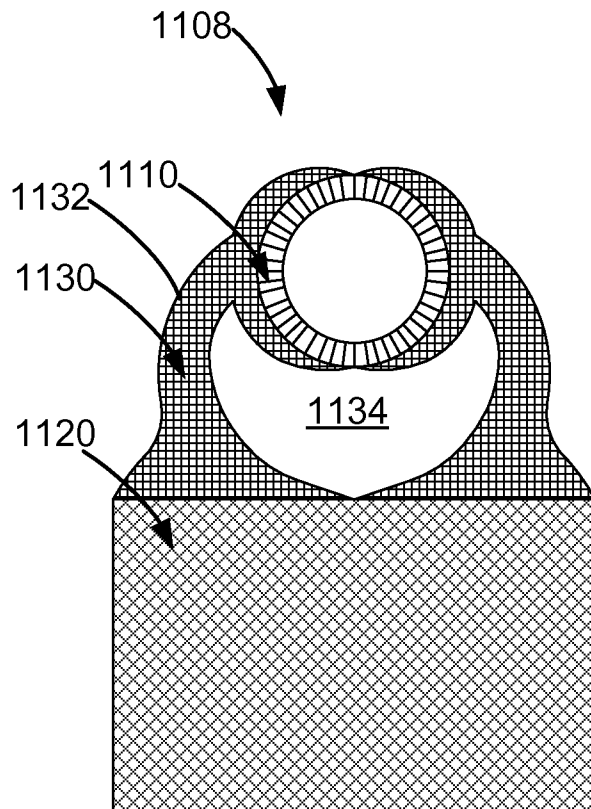


FIG. 11

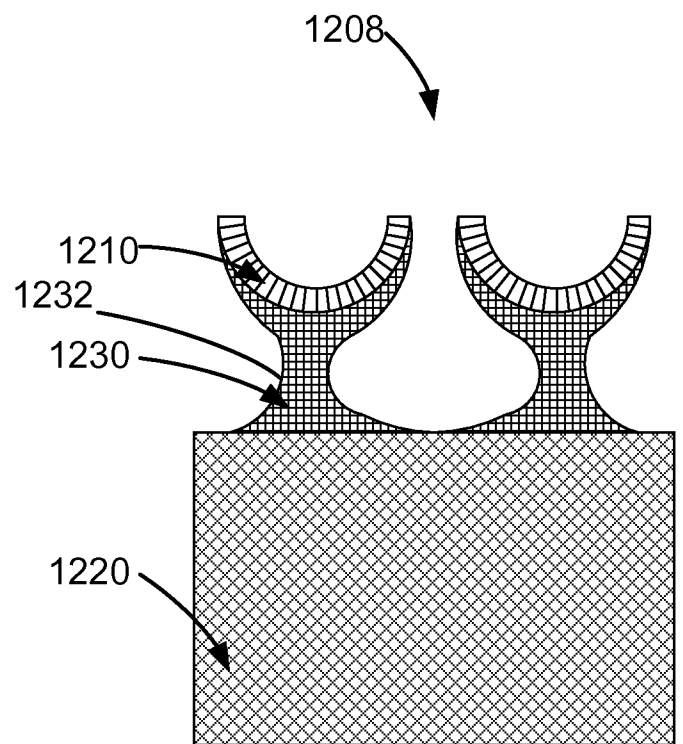


FIG. 12

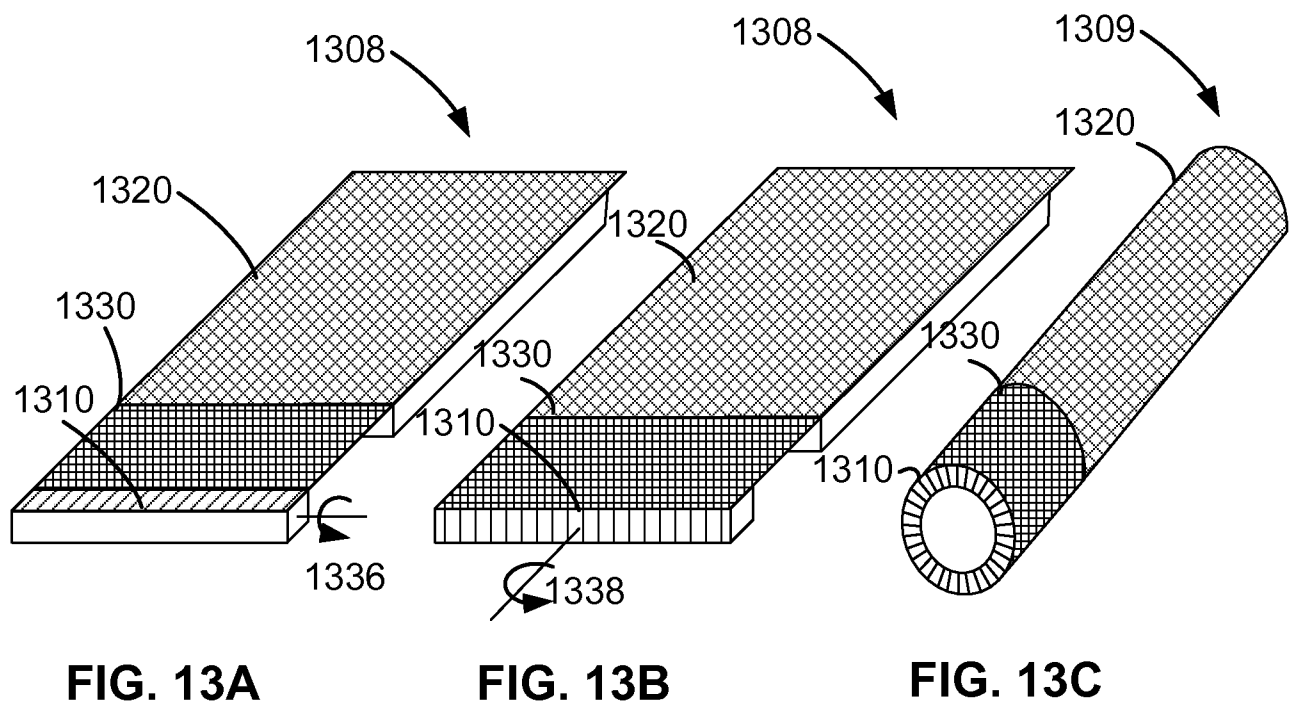


FIG. 14.1

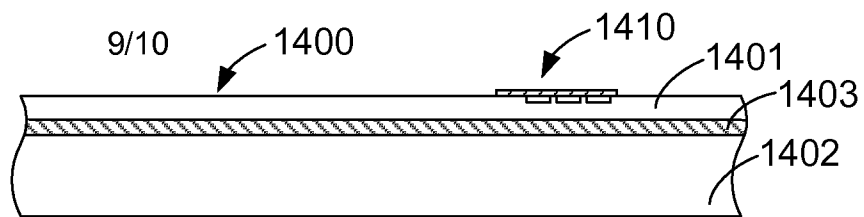


FIG. 14.2

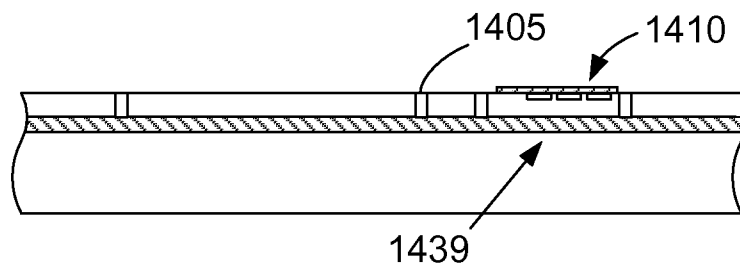


FIG. 14.3

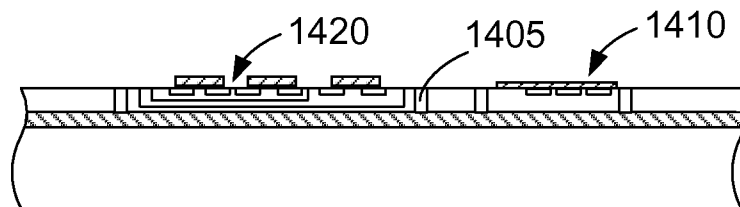


FIG. 14.4

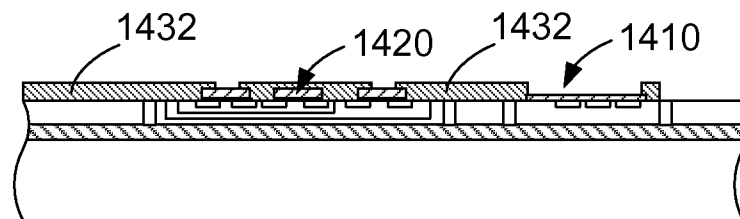


FIG. 14.5

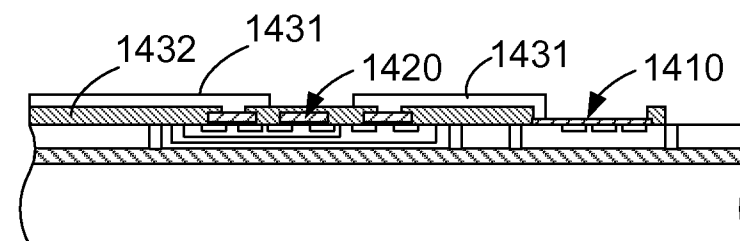


FIG. 14.6

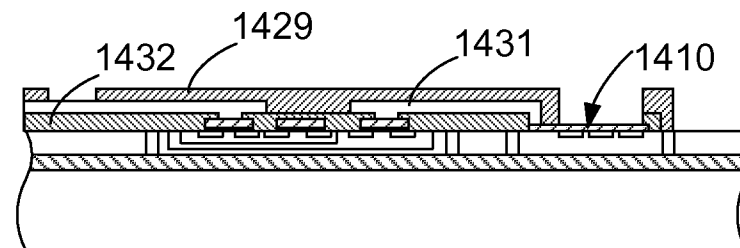


FIG. 14.7

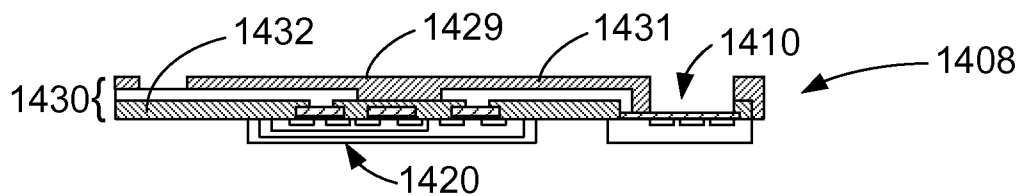


FIG. 15.1

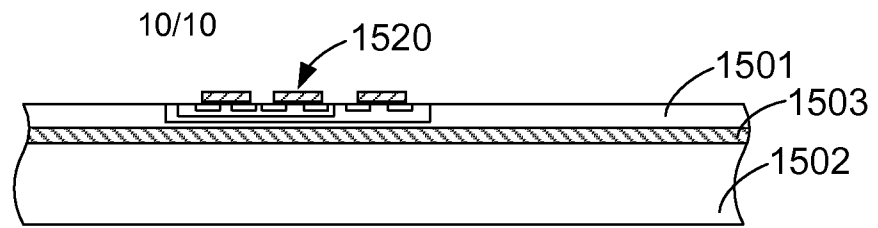


FIG. 15.2

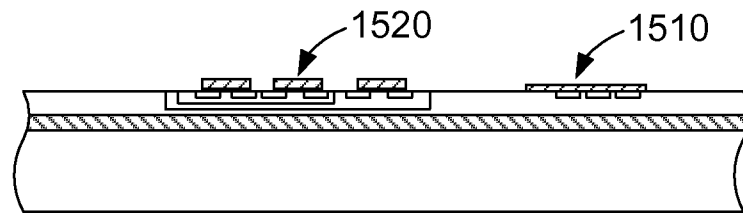


FIG. 15.3

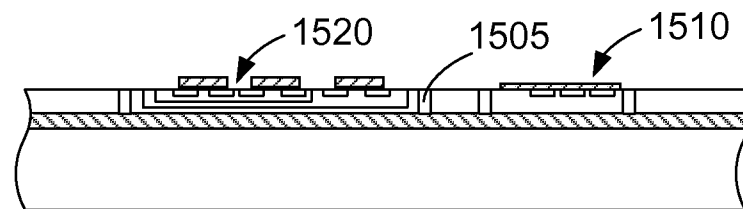


FIG. 16.1

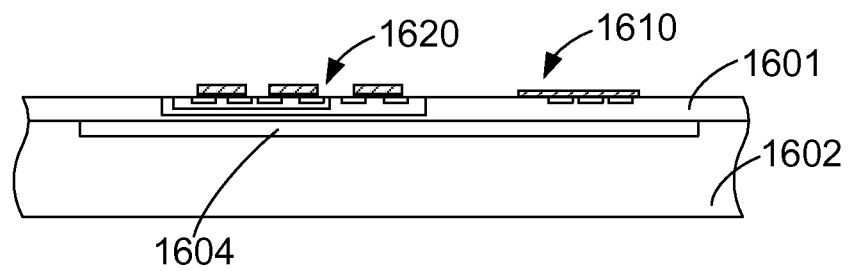
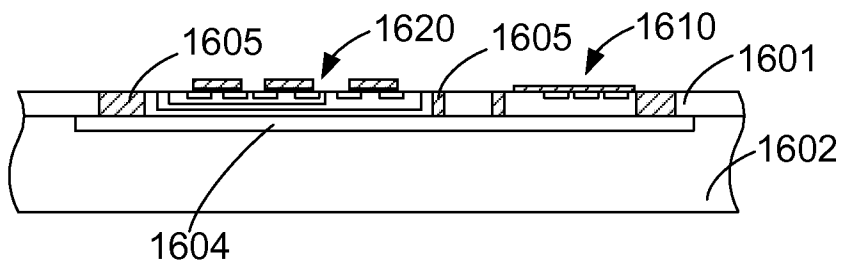


FIG. 16.2



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2008/085446

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - A61B 8/12 (2009.01)

USPC - 600/466

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - A61B 8/12 (2009.01)

USPC - 600/459,466

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO EAST System (US, USPG-PUB, EPO, JPO, DERWENT), GoogleScholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- Y	US 6,776,763 B2 (NIX et al) 17 August 2004 (17.08.2004) entire document	1, 8 ----- 2-7, 9-29
Y	US 2007/0066902 A1 (WILSER et al) 22 March 2007 (22.03.2007) entire document	2-7, 9, 11, 13-15, 18, 20, 27-29
Y	US 2006/0084875 A1 (KNIGHT) 20 April 2006 (20.04.2006) entire document	10, 12, 17-26
Y	US 6,958,255 B2 (KHURI-YAKUB et al) 25 October 2005 (25.10.2005) entire document	7
Y	US 2005/0177045 A1 (DEGERTEKIN et al) 11 August 2005 (11.08.2005) entire document	15, 24, 26
Y	US 2006/0229659 A1 (GIFFORD et al) 12 October 2006 (12.10.2006) entire document	16
Y	US 6,709,392 B1 (SALGO et al) 23 March 2004 (23.03.2004) entire document	23

☐ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

29 January 2009

Date of mailing of the international search report

06 FEB 2009

Name and mailing address of the ISA/US

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PCT OSP: 571-272-7774

专利名称(译)	使用电容式微机械超声换能器 (CMUTS) 构建的超声扫描仪		
公开(公告)号	EP2217151A1	公开(公告)日	2010-08-18
申请号	EP2008856642	申请日	2008-12-03
[标]申请(专利权)人(译)	科隆科技公司		
申请(专利权)人(译)	KOLO TECHNOLOGIES , INC.		
当前申请(专利权)人(译)	KOLO TECHNOLOGIES , INC.		
[标]发明人	HUANG YONGLI		
发明人	HUANG, YONGLI		
IPC分类号	A61B8/12		
CPC分类号	A61B8/12 A61B8/445 A61B8/4483 A61B8/4488 B06B1/0292 B06B1/0651 B06B3/00 H04R31/00 Y10T29/49005		
优先权	60/992020 2007-12-03 US 61/024843 2008-01-30 US		
外部链接	Espacenet		

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。