US009085012B2

(12) **United States Patent**
**Machida et al.**

(10) **Patent No.: US 9,085,012 B2**
(45) **Date of Patent: Jul. 21, 2015**

(54) **ULTRASONIC TRANSDUCER AND ULTRASONIC DIAGNOSTIC APPARATUS PROVIDED WITH SAME**

(75) Inventors: **Shuntaro Machida**, Kokubunji (JP); **Takashi Kobayashi**, Higashimurayama (JP)

(73) Assignee: **HITACHI MEDICAL CORPORATION**, Tokyo (JP)

( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 809 days.

(21) Appl. No.: **13/321,947**

(22) PCT Filed: **May 21, 2010**

(86) PCT No.: **PCT/JP2010/058636**

§ 371 (c)(1),
(2), (4) Date: **Nov. 22, 2011**

(87) PCT Pub. No.: **WO2010/137528**

PCT Pub. Date: **Dec. 2, 2010**

(65) **Prior Publication Data**

US 2012/0069701 A1 Mar. 22, 2012

(30) **Foreign Application Priority Data**

May 25, 2009 (JP) ................................ 2009-124840

(51) **Int. Cl.**
***B06B 1/02*** (2006.01)
***B81B 3/00*** (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ............ ***B06B 1/0292*** (2013.01); ***B81B 3/0021*** (2013.01); ***G01N 29/2406*** (2013.01); ***H04R 19/005*** (2013.01); *A61B 8/00* (2013.01); *A61B 8/4483* (2013.01); *B81B 2201/0257* (2013.01)

(58) **Field of Classification Search**
CPC .................... B81B 3/0021; B81B 2201/0257; B06B 1/0292; A61B 8/4483; A61B 8/4488; H04R 19/005; G01N 29/2406
USPC .......... 600/459; 257/416; 381/175; 310/334; 367/140
See application file for complete search history.

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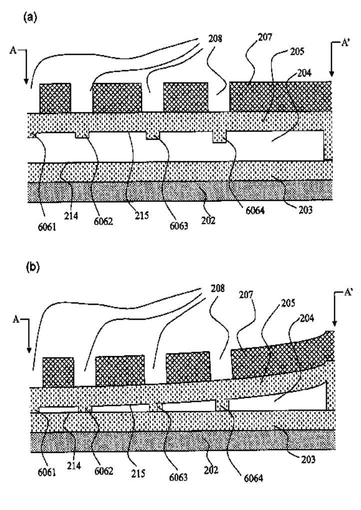
*Primary Examiner* — Ari M Diacou
(74) *Attorney, Agent, or Firm* — Brundidge & Stanger, P.C.

(57) **ABSTRACT**

For disposing projections of insulating film protruding into a hollow part in CMUT in order to suppress injection of electrical charge into the insulating film due to contact of a lower surface of a membrane with a lower surface of the hollow part, there are provided a structure of disposed projections preferred for suppressing increase in driving voltage for CMUT and decrease in receiving sensitivity, and an ultrasonic diagnostic apparatus using the same. The ultrasonic transducer of the present invention comprises a first electrode, a lower insulating film formed on the first electrode, an upper insulating film provided so as to form a hollow part above the lower insulating film, and a second electrode formed on the upper insulating film, and is characterized in that the lower insulating film or the upper insulating film has projections on the side of the hollow part, and the first electrode or the second electrode has openings formed at positions corresponding to the positions at which the projections are formed.

**15 Claims, 12 Drawing Sheets**



(51) **Int. Cl.**

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|---|---|
| ***G01N 29/24*** | (2006.01) |
| ***H04R 19/00*** | (2006.01) |
| *A61B 8/00* | (2006.01) |

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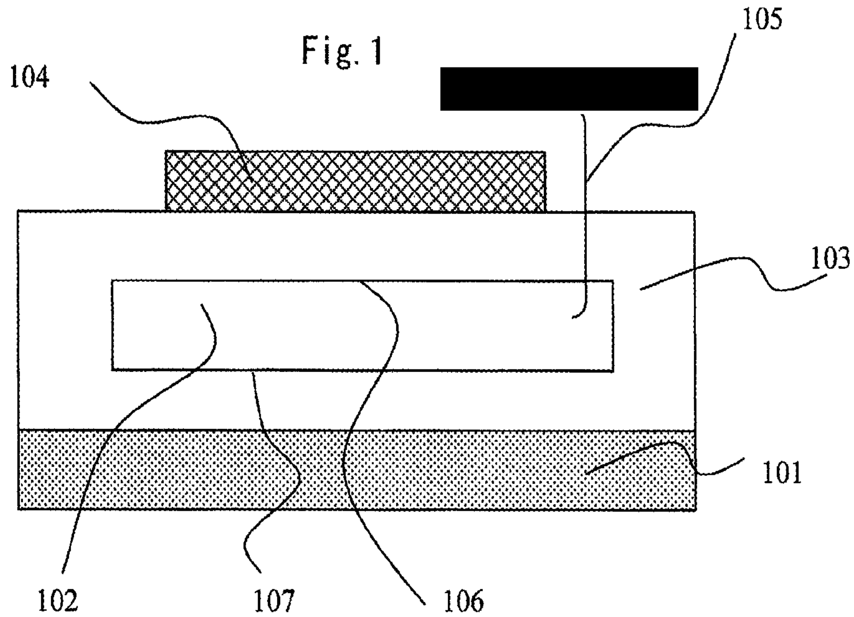
PRIOR ART

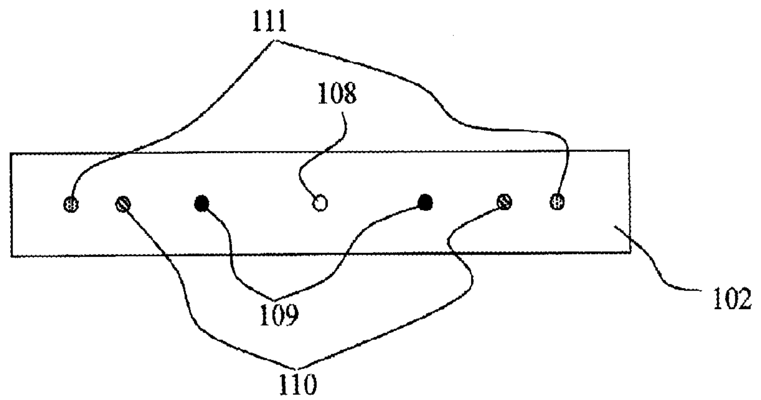
Fig. 1



PRIOR ART

Fig. 2

(a)




(b)

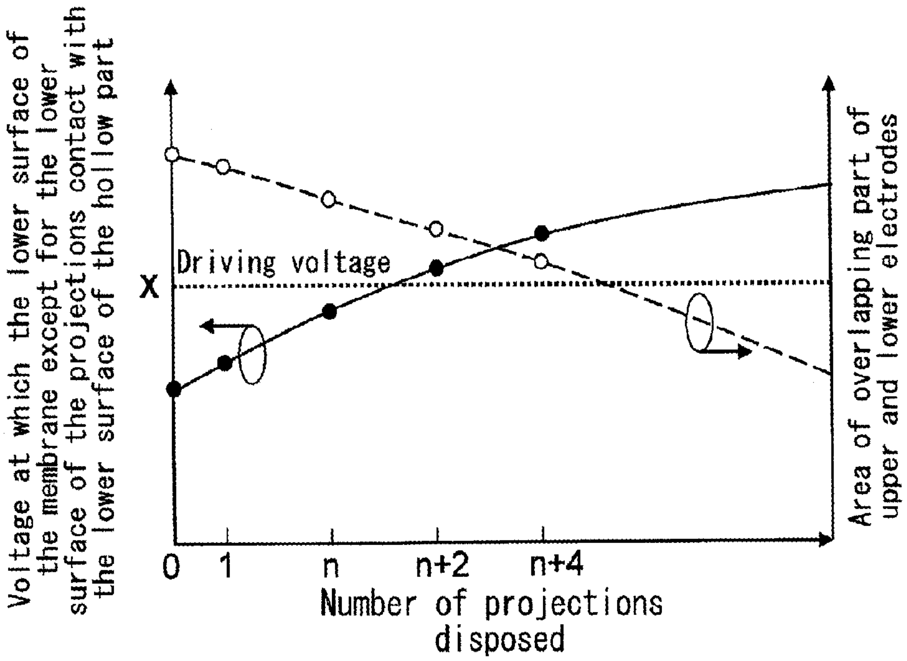


Fig. 3

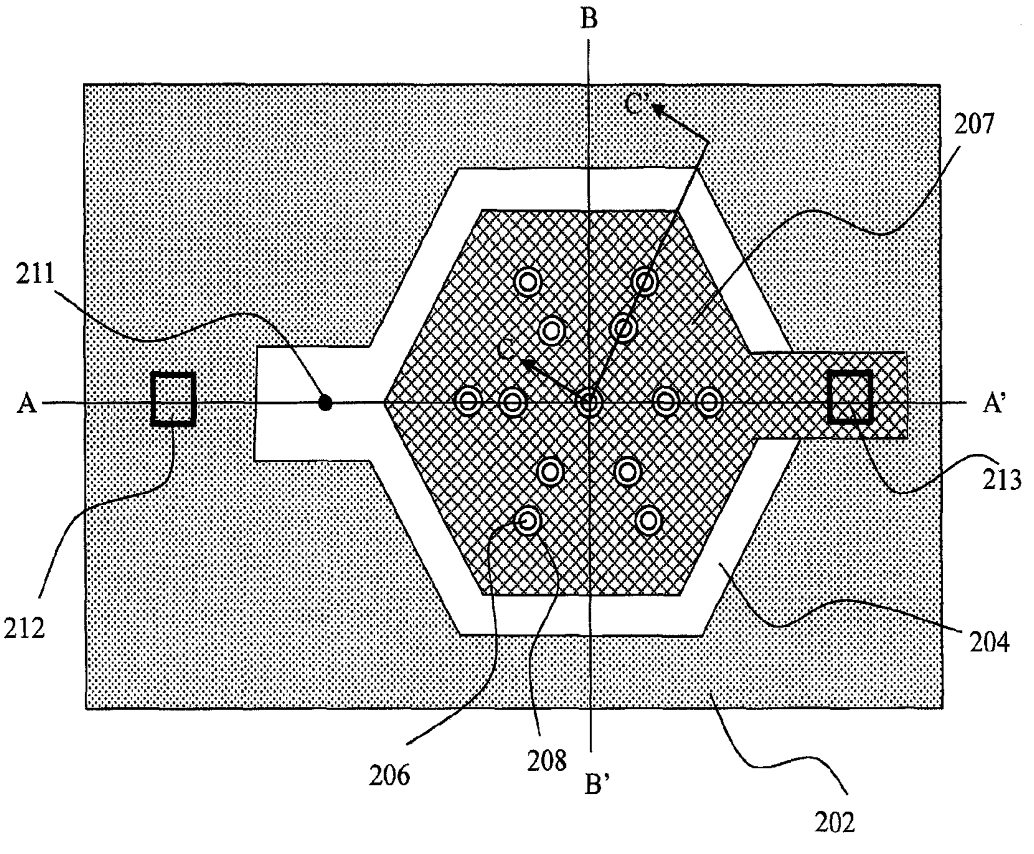


Fig. 4

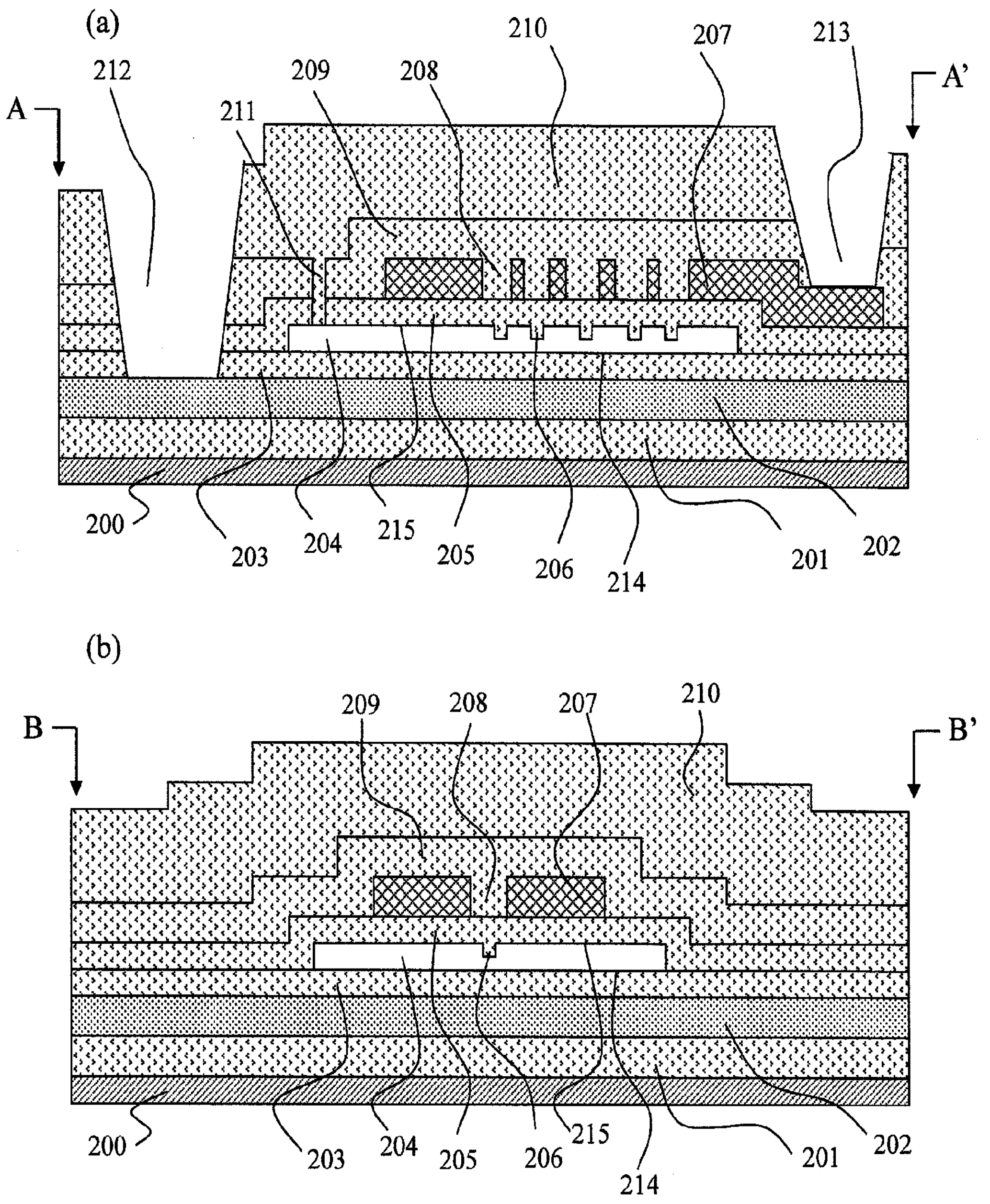
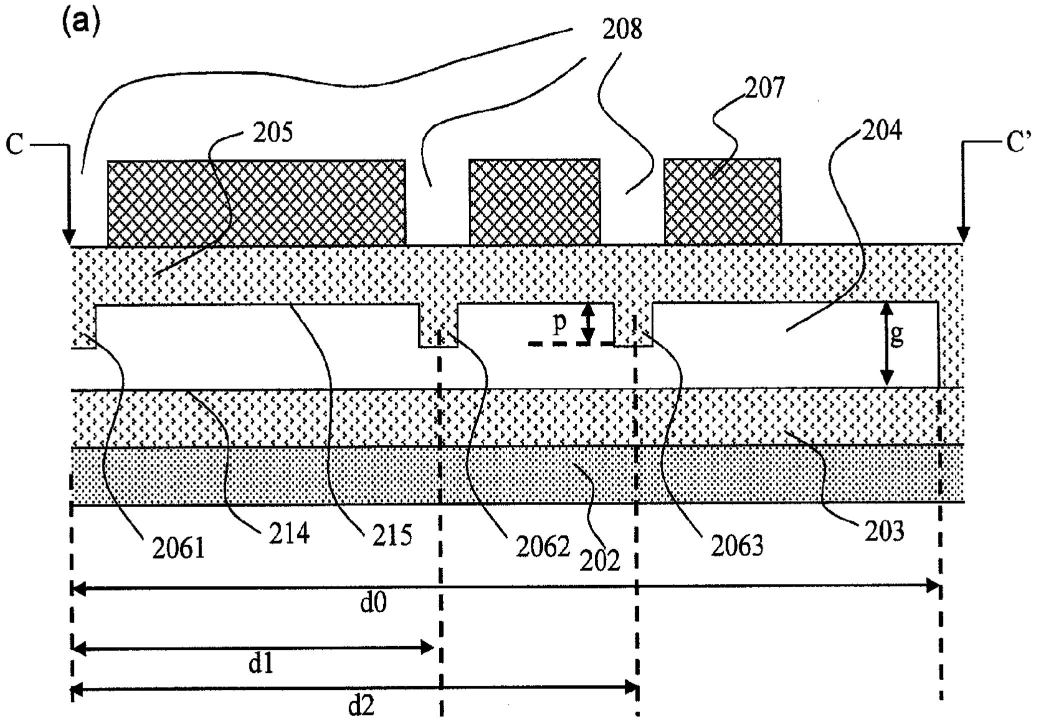

(a)
A
A'
212
209
208
210
207
213
211
200
203
204
215
205
206
214
201
202
(b)
B
B'
209
208
207
210
200
203
204
205
206
215
214
201
202

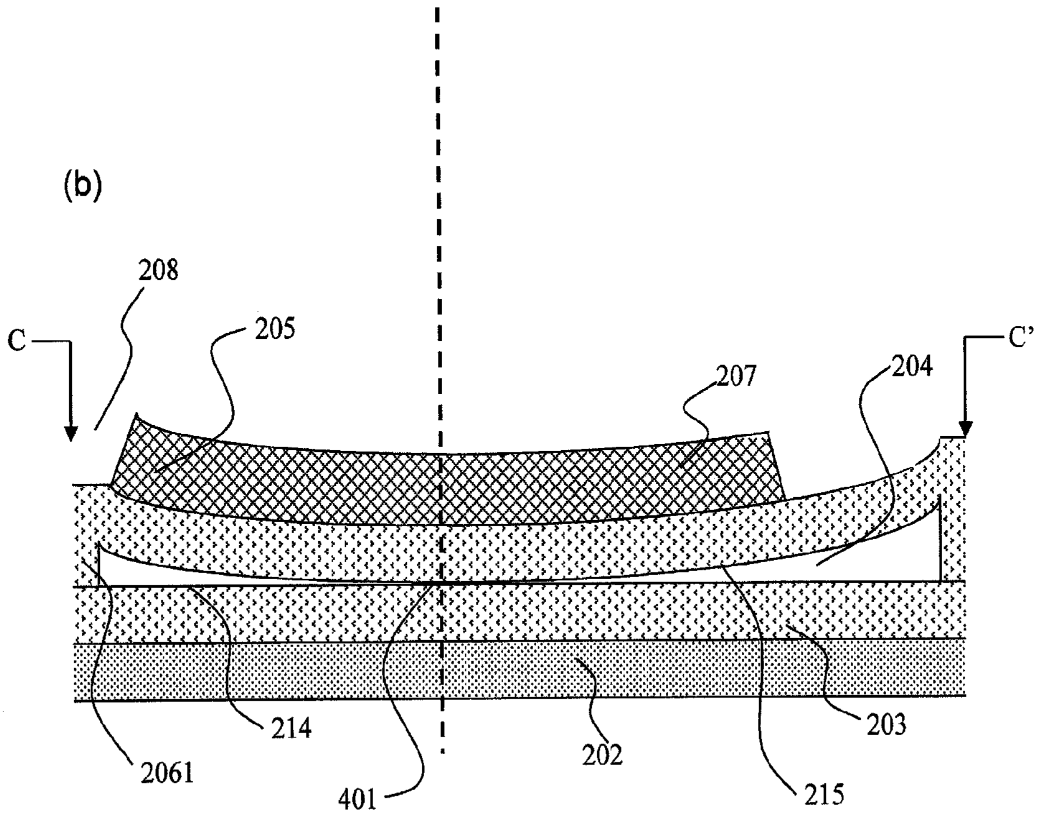
Fig. 5

(a)



208
207
205
204
C
C'
p
g
2061
214
215
2062
202
2063
203
d0
d1
d2


(b)



208
205
207
204
C
C'
2061
214
401
202
215
203

Fig. 6

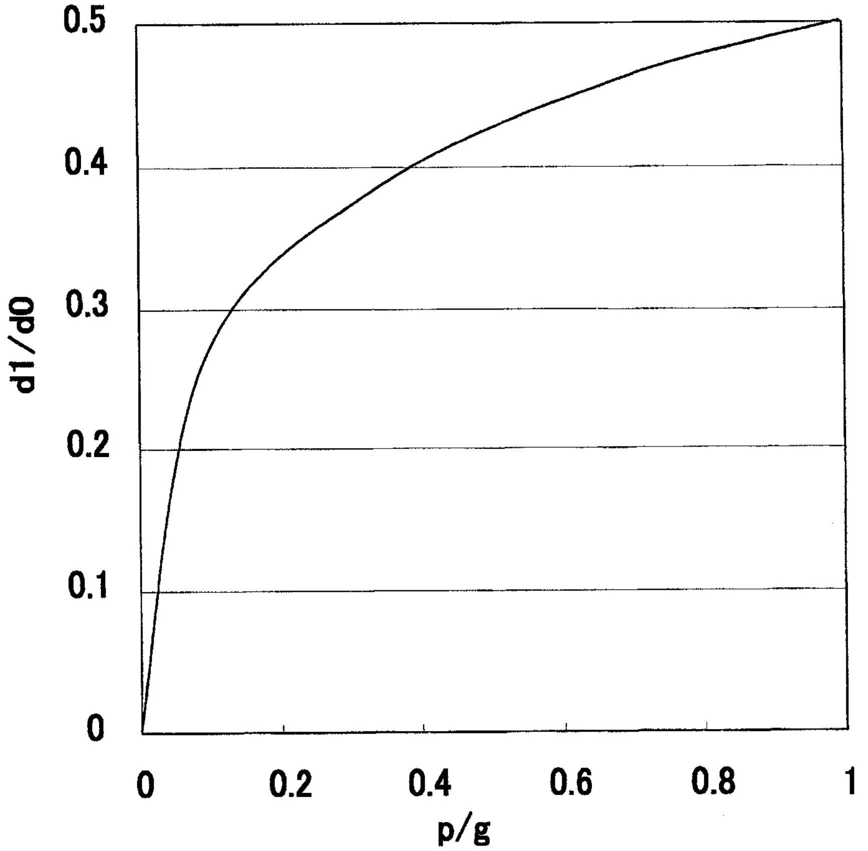


Fig. 7

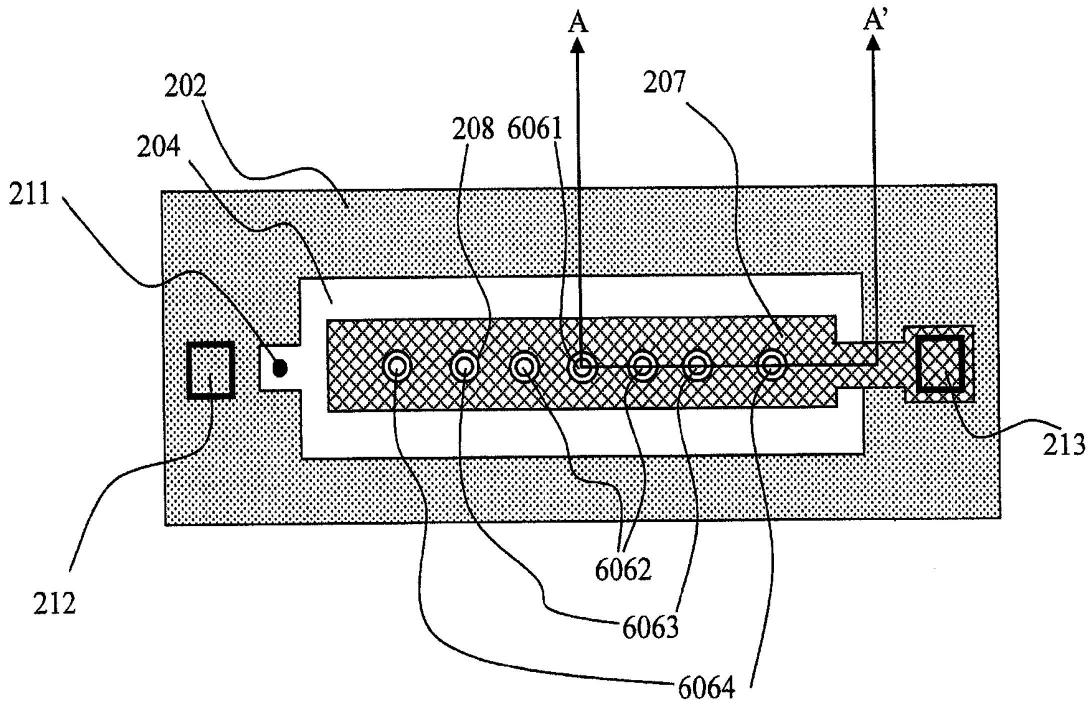
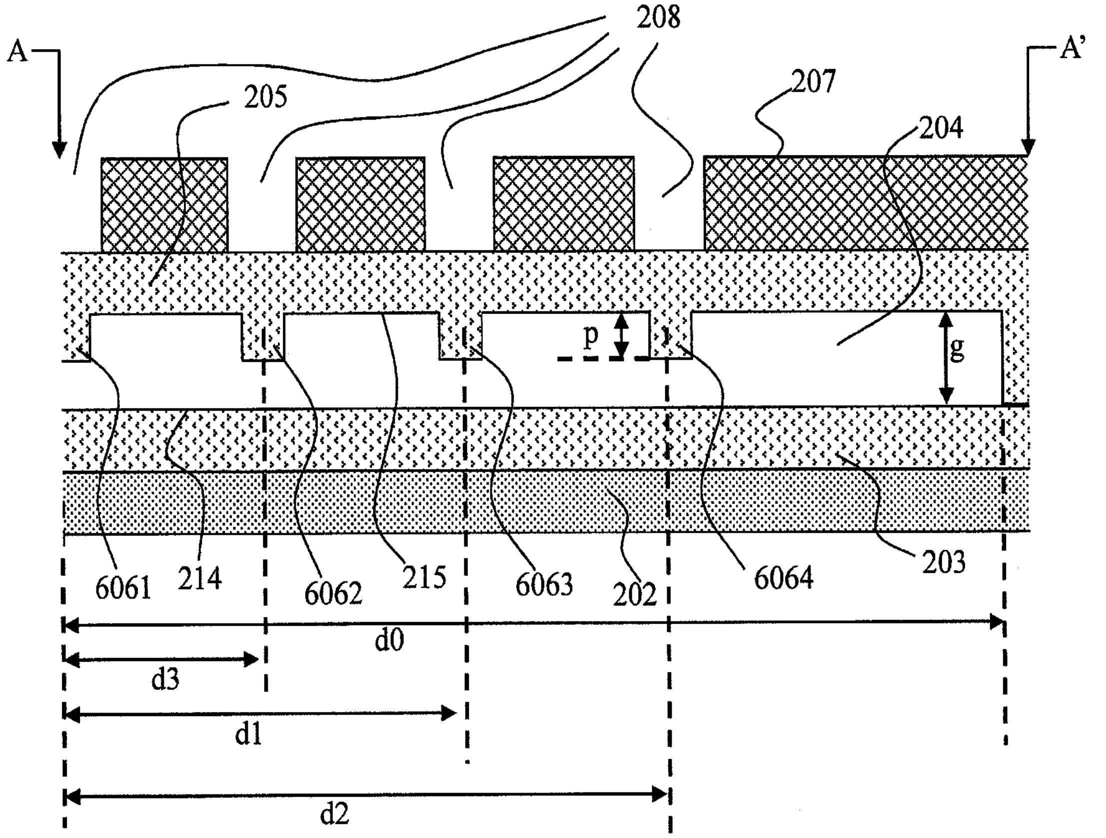


Fig. 8



A
A'
208
205
207
204
p
g
6061
214
6062
215
6063
202
6064
203
d0
d3
d1
d2

Fig. 9

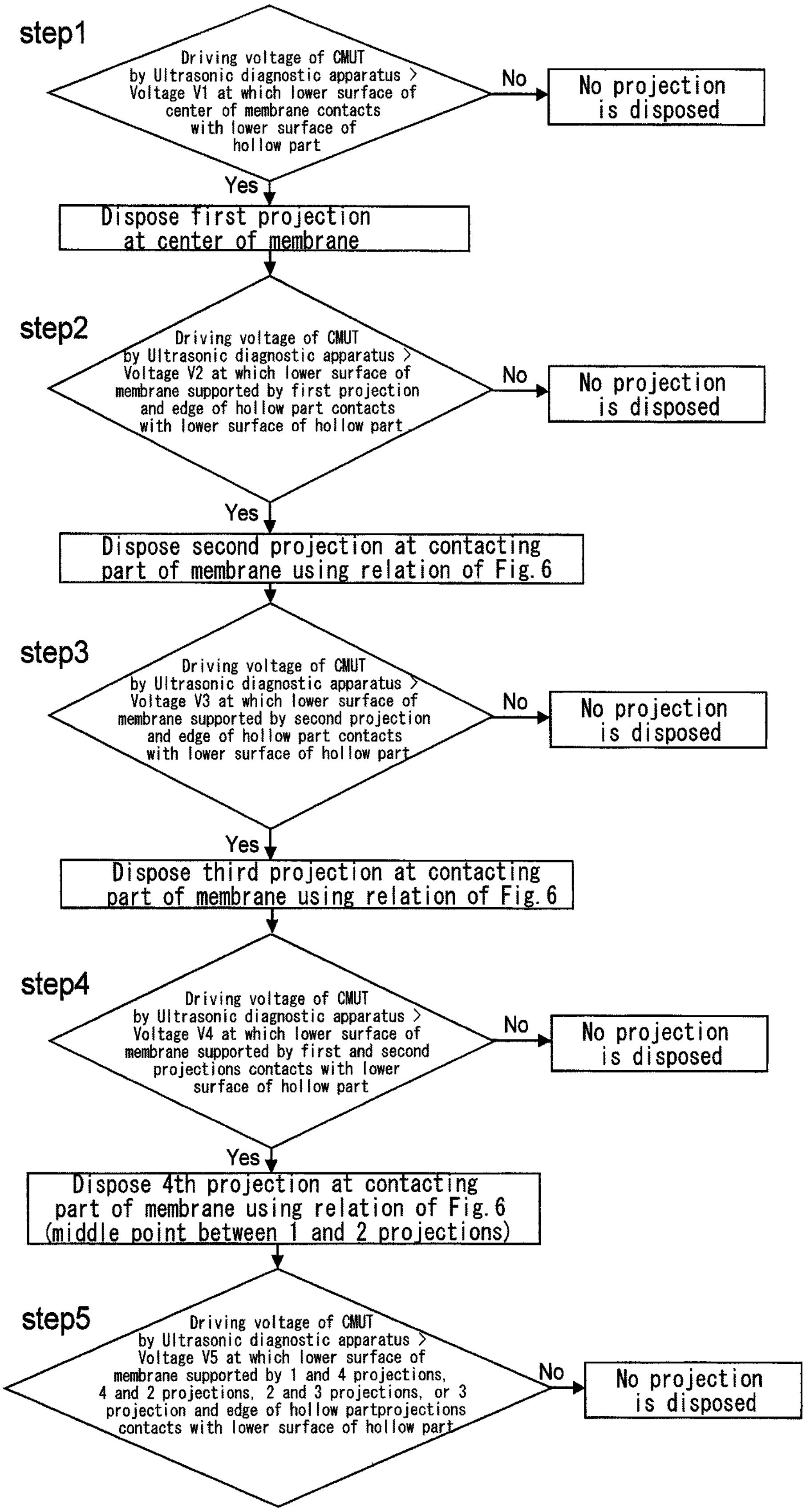
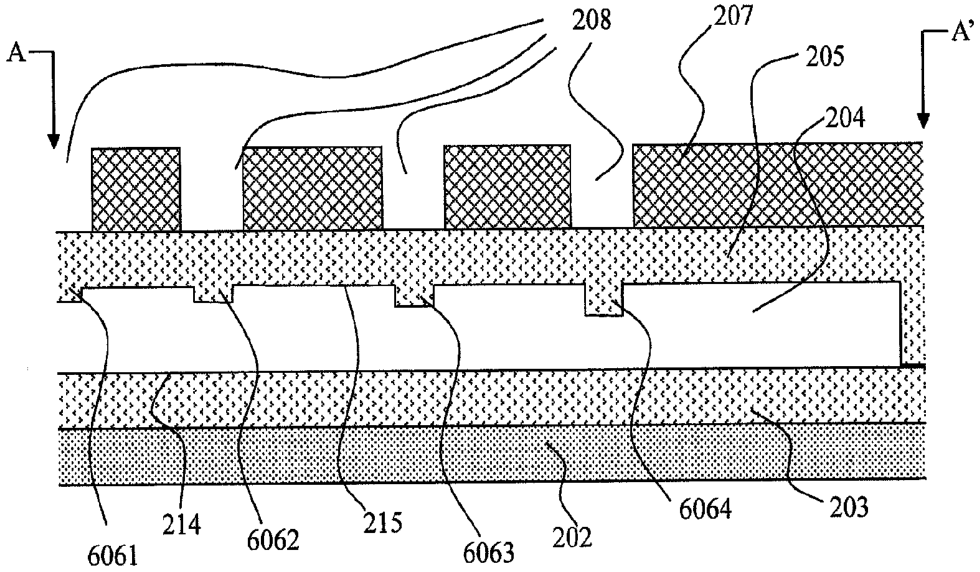

step1
Driving voltage of CMUT by Ultrasonic diagnostic apparatus > Voltage V1 at which lower surface of center of membrane contacts with lower surface of hollow part
No
No projection is disposed
Yes
Dispose first projection at center of membrane
step2
Driving voltage of CMUT by Ultrasonic diagnostic apparatus > Voltage V2 at which lower surface of membrane supported by first projection and edge of hollow part contacts with lower surface of hollow part
No
No projection is disposed
Yes
Dispose second projection at contacting part of membrane using relation of Fig. 6
step3
Driving voltage of CMUT by Ultrasonic diagnostic apparatus > Voltage V3 at which lower surface of membrane supported by second projection and edge of hollow part contacts with lower surface of hollow part
No
No projection is disposed
Yes
Dispose third projection at contacting part of membrane using relation of Fig. 6
step4
Driving voltage of CMUT by Ultrasonic diagnostic apparatus > Voltage V4 at which lower surface of membrane supported by first and second projections contacts with lower surface of hollow part
No
No projection is disposed
Yes
Dispose 4th projection at contacting part of membrane using relation of Fig. 6 (middle point between 1 and 2 projections)
step5
Driving voltage of CMUT by Ultrasonic diagnostic apparatus > Voltage V5 at which lower surface of membrane supported by 1 and 4 projections, 4 and 2 projections, 2 and 3 projections, or 3 projection and edge of hollow partprojections contacts with lower surface of hollow part
No
No projection is disposed

Fig. 10

(a)



A
A'
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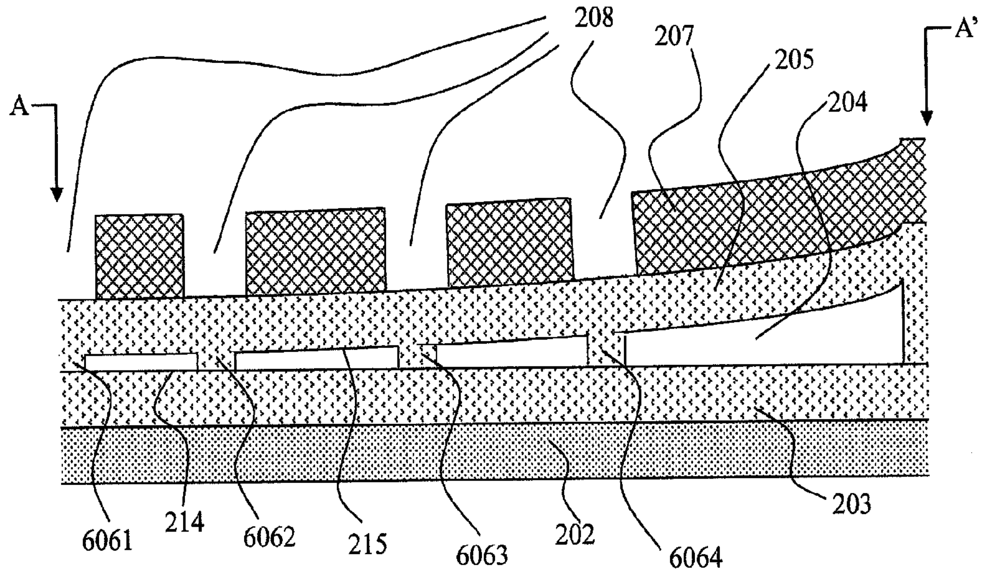
207
205
204
6061
214
6062
215
6063
202
6064
203


(b)



A
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6062
215
6063
202
6064
203

Fig. 11

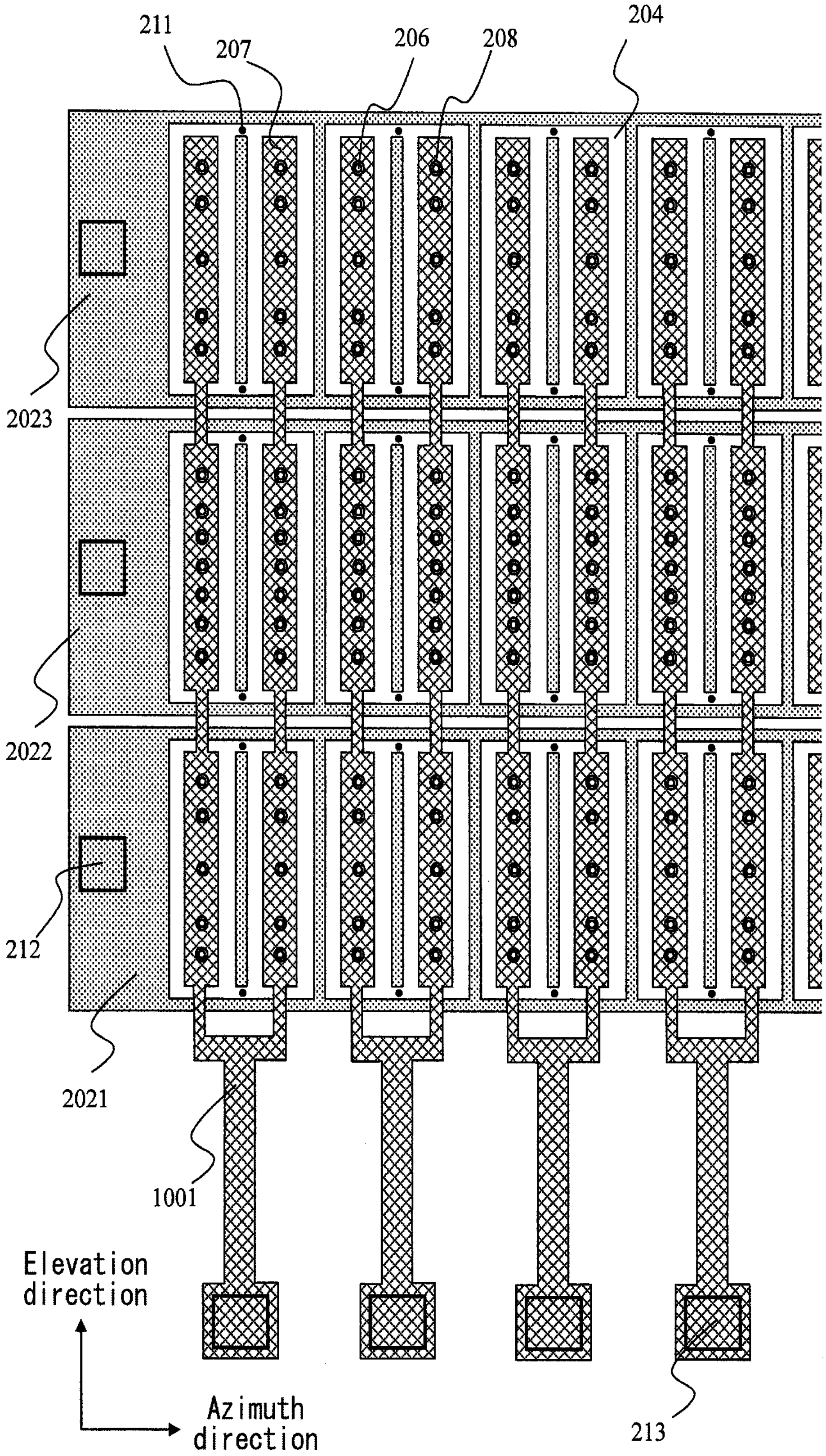
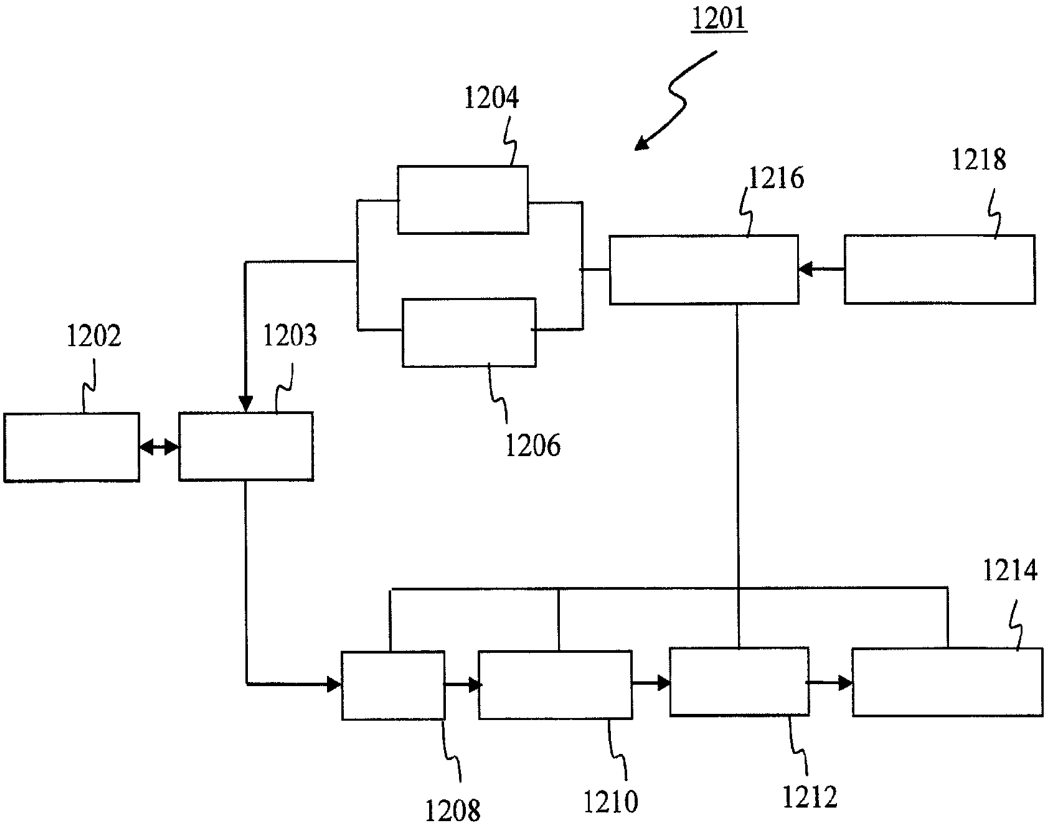

211
207
206
208
204
2023
2022
212
2021
1001
Elevation direction
Azimuth direction
213

Fig. 12



# ULTRASONIC TRANSDUCER AND ULTRASONIC DIAGNOSTIC APPARATUS PROVIDED WITH SAME

## TECHNICAL FIELD

The present invention relates to an ultrasonic transducer and an ultrasonic diagnostic apparatus using the same. In particular, the present invention relates to an ultrasonic transducer produced by the micro-electro-mechanical system (MEMS) technology, and an ultrasonic diagnostic apparatus using the same.

## BACKGROUND ART

Ultrasonic transducers, which transmit and receive ultrasonic waves, are used for apparatuses for diagnosing tumors in human bodies etc., apparatuses for performing nondestructive tests of structures etc.

As the ultrasonic transducers, those utilizing vibration of piezoelectric substances have so far been used. However, with progress of the MEMS technology in recent years, capacitive micromachined ultrasonic transducers (CMUTs) comprising a vibration part formed on a silicon substrate have been developed, and researches are actively conducted aiming at practical use thereof.

For example, U.S. Pat. No. 6,320,239 B2 (Patent document 1) discloses a single CMUT and a CMUT array.

U.S. Pat. No. 6,571,445 B2 (Patent document 2) and U.S. Pat. No. 6,562,650 B2 (Patent document 3) disclose techniques for forming CMUT in an upper layer of a signal processing circuit formed on a silicon substrate.

Further, U.S. Patent Published Application Nos. 2005/0228285 A1 (Patent document 4) and 2007/0264732 A1 (Patent document 5) disclose CMUTs having a structure comprising a projection protruding into a hollow part.

## PRIOR ART REFERENCES

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Patent document 5: U.S. Patent Published Application No. 2007/0264732 A1

## SUMMARY OF THE INVENTION

### Object to be Achieved by the Invention

In contrast to the conventional transducers utilizing a piezoelectric substance, CMUTs have advantages of the wide frequency band of usable ultrasonic waves, high sensitivity, and so forth. Moreover, since they are produced by using LSI processing techniques, micro processing can be used. In particular, it is considered that, when ultrasonic devices are arranged in the form of array and independently controlled, CMUTs become indispensable. This is because, while wiring for each device is needed and thus the number of the wiring in the array becomes a huge number, CMUTs are produced by using LSI processing techniques, and therefore the wiring is easy. Moreover, that is also because the CMUTs can be embedded on one chip of a circuit which processes signals from an ultrasonic transmission part.



With reference to FIG. 1, fundamental structure and operation of CMUT will be explained. Above a lower electrode **101**, a hollow part **102** surrounded by an insulating film **103** is formed. Above the hollow part **102**, an upper electrode **104** is disposed via the insulating film **103**. If a DC voltage and an AC voltage are superimposed between the upper electrode **104** and the lower electrode **101**, an electrostatic force is generated between the upper electrode **104** and the lower electrode **101**, and a membrane **105** constituted by the insulating film **103** and the upper electrodes **104** above the hollow part **102** vibrates at the frequency of the applied AC voltage to transmit ultrasonic waves.

In contrast, in the case of reception, the membrane **105** is vibrated by pressure of ultrasonic waves that arrive at the surface of the membrane **105**. Then, the distance between the upper electrode **104** and the lower electrode **101** changes, and therefore ultrasonic waves can be detected as change of the electrostatic capacitance.

As it is clear from the aforementioned principle of the operation, since CMUT transmits and receives ultrasonic waves by using vibration of the membrane induced by the electrostatic force resulting from application of voltage between the electrodes and capacitance change between the electrodes induced by the vibration, stability of voltage difference between the electrodes is important for stable operation and improvement in reliability of the device.

According to the aforementioned principle of operation, by applying a DC voltage between the upper electrode **104** and the lower electrode **101**, an electrostatic force is generated between the two electrodes, and the membrane is deformed, and stabilized at a deformation amount at which the spring restoring forth induced by the deformation and the electrostatic force are balanced.

CMUT is usually driven at such a DC voltage that the electrostatic force between the electrodes and the spring restoring forth are balanced. However, if a DC voltage larger than such a voltage that deformation amount of the membrane reaches about ⅓ of the distance between the electrodes, called collapse voltage, is applied, the electrostatic force between the electrodes becomes larger than the spring restoring force of the membrane, thus the membrane cannot be stabilized at a fixed position, but a lower surface **106** of the membrane contacts with a lower surface **107** of the hollow part. If they contact, there is produced a structure that the insulating film **103** is held between the upper electrode and the lower electrode, and electrical charge is injected into the film from the two electrodes to generate fixed electrical charge in the film. Even if a DC voltage is applied again between the two electrodes, the electric field between the electrodes is shielded by the fixed electrical charge in the insulating film, and the voltage used for optimal operation of CMUT is changed. Therefore, the CMUTs disclosed in Patent documents 1, 2 and 3 are usually used with a voltage significantly lower than the collapse voltage in order to prevent the lower surface of the membrane from contacting with the lower surface of the hollow part.

However, in order to improve the sensitivity for transmission and reception, it is necessary to make the distance between the electrodes as short as possible during use of CMUT, and therefore it is important to apply a voltage as close to the collapse voltage as possible between the electrodes.

Moreover, in order to improve transmitting sound pressure of the ultrasonic waves, it is desirable to maximize the vibration amplitude of the membrane **105**. However, in order to prevent the lower surface **106** of the membrane from contacting with the lower surface **107** of the hollow part and not to inject electrical charge into the insulating film during the vibration, the AC voltage to be superimposed on the DC voltage must also be a voltage significantly lower than the voltage at which the lower surface of the membrane contacts with the lower electrode or the insulating film under the hollow part.

Patent document 4 mentioned above discloses a structure that a projection of the insulating film protruding into the hollow part of CMUT is formed so that the projection serves as a support pillar, and thus the lower surface of the membrane except for the lower surface of the projection does not contact with the lower surface of the hollow part, even if a DC voltage or an AC voltage higher than the collapse voltage is applied. However, since it has a structure that the projection is positioned between the upper and lower electrodes, accumulation of electrical charge in the insulating film of the projection cannot be avoided.

In contrast, the CMUT of Patent document 5 has a structure that the projection of the insulating film protruding into the hollow part is not put between the upper and lower electrodes, and therefore accumulation of electrical charge in the insulating film of the projection can be avoided even when the lower surface of the projection contacts with the lower surface of the hollow part. However, if a large number of projections are disposed, the area of the overlapping part of the upper and lower electrodes correspondingly becomes small, which results in increase in driving voltage of CMUT and decrease in reception sensitivity, as is also clear from the aforementioned principle of the operation of CMUT. This situation is schematically shown in FIG. **2**. FIG. **2**, (a) is a schematic view of disposition pattern of projections of the insulating film protruding into the hollow part **102** seen from above. The hollow part has a rectangular shape as seen from above, and there are shown a projection **108** of the insulating film disposed at the center of the membrane locating above the hollow part, and representatively shown the n-th projections **109** of the insulating film, (n+2)th projections **110** of the insulating film, and the (n+4)th projections **111** of the insulating film among the projections disposed on both sides of the projection **108**. Since the hollow part **102** has a rectangular shape, the membrane is symmetrically deformed by the voltage with respect to the projection **108** at the center of the membrane, and when the projections are disposed one after another, the number of the projections is increased by 2 at a time. If the number of the projections is increased from n to n+2, n+4, . . . , the voltage at which the lower surface of the membrane except for the lower surfaces of the projections contacts with the lower surface of the hollow part increases, and the area of the overlapping parts of the upper and lower electrodes decreases. This relation is schematically shown in FIG. **2**, (b). As seen from FIG. **2**, (b), in which X represents the driving voltage (volt) for CMUT for obtaining transmission and reception sensitivity for ultrasonic waves and transmitting sound pressure required for ultrasonic diagnosis, if the number of the projections is n, when the membrane vibrates, the lower surface of the membrane except for the lower surfaces of the projections contacts with the lower surface of the hollow part, and accumulation of electrical charge in the insulating film cannot be obviated. However, if the projections are increased without any restriction, the area of the overlapping parts of the upper and lower electrodes decreases, and receiving sensitivity becomes lower. In such a case, if n+2 of the projections are disposed, although the lower surfaces of n+2 of the projections contact with the lower surface of the hollow part at the driving voltage, they serve as support pillars, therefore the lower surface of the membrane except for the lower surfaces of the projections does not contact with the lower surface of the hollow part, thus accumulation of electrical charge in the insulating film can be suppressed, and decrease of the area of the overlapping parts of the upper and lower electrodes can also be suppressed.

Based on the above, an object of the present invention is, for disposing projections of insulating film protruding into a hollow part in CMUT, to provide a method for determining disposing positions and number of the projections, an ultrasonic transducer having projections of insulating film formed according to the disposition method, and an ultrasonic diagnostic apparatus using it.

The aforementioned object and the other objects as well as the novel characteristics of the present invention will become apparent from the descriptions of this specification and the appended drawings.

## Means for Achieving the Object

Brief explanations of the outlines of the representative embodiments of the present invention disclosed in this application are as follows.

The ultrasonic transducer of the present invention is an ultrasonic transducer comprising a first electrode, a lower insulating film formed on the first electrode, an upper insulating film provided so as to form a hollow part above the lower insulating film, and a second electrode formed on the upper insulating film, wherein the lower insulating film or the upper insulating film has projections formed on the side of the hollow part, and the first electrode or the second electrode has openings formed at positions corresponding to the positions at which the projections are formed.

The ultrasonic transducer of the present invention may be characterized in that a first projection is formed on the upper insulating film or the lower insulating film at a position corresponding to the center of a membrane consisting of at least the upper insulating film and the second electrode.

The ultrasonic transducer of the present invention may be characterized in that a second projection is formed between the first projection and an edge of the hollow part, and, provided that the first projection is contacted with the upper insulating film or the lower insulating film and a part of the membrane on a straight line connecting the first projection and an edge of the hollow part is contacted with the lower insulating film by driving voltage applied to the first electrode and the second electrode, the second projection is formed at the contacting part of the membrane.

The ultrasonic transducer of the present invention may be characterized in that a third projection is formed between the second projection and the edge of the hollow part, and provided that a part of the membrane on a straight line connecting the second projection and the edge of the hollow part is contacted with the lower insulating film by driving voltage applied to the first electrode and the second electrode, the third projection is formed on the contacting part of the membrane.

The ultrasonic transducer of the present invention may be characterized in that a third projection is formed between the second projection and the edge of the hollow part, and provided that a part of the membrane on the straight line connecting the second projection and the edge of the hollow part is contacted with the lower insulating film by driving voltage applied to the first electrode and the second electrode, the third projection is formed at a position shifted to the first projection side from the contacting part of the membrane.

The ultrasonic transducer of the present invention may be characterized in that, provided that the membrane is contacted with the lower insulating film between the first projection and the second projection by driving voltage applied to the first electrode and the second electrode, a third projection is further formed at the middle point between the first projection and the second projection.

The ultrasonic transducer array of the present invention comprises the ultrasonic transducers disposed in an array, wherein the ultrasonic transducers have different disposition patterns of projections.

Further, the ultrasonic diagnostic apparatus of the present invention comprises an ultrasonic probe for transmitting and receiving ultrasonic waves to or from a subject, an image processing part for constituting an ultrasonogram on the basis of received ultrasonic signals outputted from the ultrasonic probe, and a display part for displaying the ultrasonogram, wherein the ultrasonic probe is an ultrasonic transducer comprising a first electrode, a lower insulating film formed on the first electrode, an upper insulating film provided so as to form a hollow part above the lower insulating film, and a second electrode formed on the upper insulating film, wherein the lower insulating film or the upper insulating film has projections formed on the side of the hollow part, and the first electrode or the second electrode has openings formed at positions corresponding to the positions at which the projections are formed.

The ultrasonic diagnostic apparatus of the present invention may be characterized by using an ultrasonic transducer in which a first projection is formed on the upper insulating film or the lower insulating film at a position corresponding to the center of the membrane consisting of at least the upper insulating film and the second electrode.

The ultrasonic diagnostic apparatus of the present invention may be characterized by using the ultrasonic transducer, wherein, provided that the first projection is contacted with the upper insulating film or the lower insulating film and a part of the membrane on a straight line connecting the first projection and an edge of the hollow part is contacted with the lower insulating film by driving voltage applied to the first electrode and the second electrode, a second projection is formed on the contacting part of the membrane.

The ultrasonic diagnostic apparatus of the present invention may be characterized by using the ultrasonic transducer, wherein, provided that a part of the membrane on a straight line connecting the second projection and the edge of the hollow part is contacted with the lower insulating film by driving voltage applied to the first electrode and the second electrode, a third projection is formed on the contacting part of the membrane.

The ultrasonic diagnostic apparatus of the present invention may be characterized by using the ultrasonic transducer, wherein, provided that the membrane is contacted with the lower insulating film at a position on the straight line connecting the second projection and the edge of the hollow part by driving voltage applied to the first electrode and the second electrode, a third projection is formed at a position shifted to the first projection side from the contacting part of the membrane.

The ultrasonic diagnostic apparatus of the present invention may be characterized by using the ultrasonic transducer, wherein, provided that the membrane is contacted with the lower insulating film between the first projection and the second projection by driving voltage applied to the first electrode and the second electrode, the third projection is formed at the middle point between the first projection and the second projection.

The ultrasonic diagnostic apparatus of the present invention may be characterized by using an ultrasonic transducer array comprising the ultrasonic transducers disposed in an array, wherein the ultrasonic transducers have different disposition patterns of projections.

## Effect of the Invention

Effects obtainable by the representative embodiments of the present invention among those disclosed in this application are briefly explained as follows.

According to the present invention, when a CMUT is contemplated, in which projections of an insulating film protruding into a hollow part are disposed in order to suppress injection of electrical charge into the insulating film due to contact thereof between a lower surface of the hollow part and a lower surface of the membrane, there can be provided a ultrasonic transducer (CMUT) having a projection disposition structure suitable for suppressing increase in driving voltage of the CMUT and decrease in receiving sensitivity, and an ultrasonic diagnostic apparatus using the same.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional view of an ultrasonic transducer examined by the inventors of the present invention.

FIG. **2**, (a) is a schematic view of a disposition pattern of projections for disposing projections in a hollow part, which is seen from above, and (b) is a graph showing the relation between number of disposed projections and overlapping area of upper and lower electrodes, and the relation between number of disposed projections and voltage (contact voltage) at which the lower surface of the membrane except for projections contacts with the lower surface of the hollow part.

FIG. **3** is a top view of the ultrasonic transducer according to the embodiment 1 of the present invention, in which the hollow part has a hexagonal shape as seen from above.

FIG. **4**, (a) is a sectional view along the line A-A' drawn in FIG. **3**, and (b) is a sectional view along the line B-B' drawn in FIG. **3**.

FIG. **5**, (a) shows a sectional along the line C-C' drawn in FIG. **3**, showing a state that voltage for driving the CMUT is not applied, and (b) shows a section along the line C-C' drawn in FIG. **3**, showing a CMUT where the projections **2062** and **2063** are not disposed, but only the projection **2061** is disposed, and which is driven by an ultrasonic diagnostic apparatus, so that the projection **2061** contacts with the lower surface **214** of the hollow part, and the lower surface **215** of the membrane contacts with the lower surface **214** of the hollow part.

FIG. **6** is a graph showing the relation of the distance d1 indicating disposing position of a projection, length p of the projection, thickness g of the hollow part, and distance d0 between the center of the membrane and the edge of the hollow part.

FIG. **7** is a top view of the ultrasonic transducer according to the embodiment 1 of the present invention, in which the hollow part has a rectangular shape as seen from above.

FIG. **8** shows a section along the line A-A' drawn in FIG. **7**, showing a state that voltage for driving the CMUT is not applied.

FIG. **9** is a flowchart for determining whether it is necessary to dispose a projection for the case that projections of an insulating film are disposed in the embodiment 1 of the present invention.

FIG. **10** shows sections along the line A-A' drawn in FIG. **7**, in which the projections of the insulating film have different lengths: (a) shows a state that voltage for driving the CMUT is not applied, and (b) shows a state that voltage for driving the CMUT is applied, and the projections of the insulating film contact with the lower surface of the hollow part.

FIG. **11** is a top view of a chip on which the ultrasonic transducers are disposed in an array according to the embodiment 2 of the present invention.

FIG. **12** is a configurational diagram of the ultrasonic diagnostic apparatus of the present invention.

## MODES FOR CARRYING OUT THE INVENTION

Hereafter, embodiments of the present invention will be explained in detail with reference to the drawings. In all the drawings for explaining the embodiments, the same members are basically indicated with the same numerals, and repetitive explanations for them are omitted.

In the following explanations of the embodiments, explanations are made with several sections or for several embodiments for convenience, as required, but they are mutually related, and are in such a relation that one of them is modification, details, supplemental explanation or the like of a part or all of the other, unless especially indicated.

Moreover, in the following explanations of the embodiments, when a number of an element (including number, numerical value, quantity, range etc.) or the like is mentioned, the number is not limited to that specific number, and may be larger or smaller than the mentioned number, except for the case where it is explicitly indicated that the number should be the specifically mentioned number, or it is theoretically clear that the number should be limited to the specifically mentioned number.

Furthermore, in the embodiments mentioned below, it is of course that the constituent elements thereof (including steps as elements etc.) are not necessarily indispensable, except for the case where it is explicitly indicated that a specific element is indispensable, or it is theoretically clear that a specific element is indispensable.

Similarly, in the following explanations of the embodiments, when shapes, positional relationship etc. of the constituent elements are mentioned, they include substantially similar or analogous shapes and so forth, except for the case where it is explicitly indicated, or it is theoretically clear that the above is not true. This shall also apply to the numerical values and ranges mentioned above.

In addition, even in a plane view, hatching may be used for ease of understanding.

<Ultrasonic Transducer>

In the following embodiment, the object of producing an ultrasonic transducer comprising suitably disposed projections of an insulating film protruding into a hollow part is achieved by determining disposing position of a projection and necessity of disposition of a projection on the basis of determining which one of driving voltage for the ultrasonic transducer applied by an ultrasonic diagnostic apparatus and voltage at which the lower surface of the membrane contacts with the lower surface of the hollow part is larger than the other.

### Embodiment 1

A structure of an ultrasonic transducer (CMUT) according to the embodiment 1 of the present invention will be explained with reference to FIGS. **3** and **4**. FIG. **3** is a top view of the ultrasonic transducer (CMUT) of this embodiment 1. FIG. **4**, (a) is a sectional view along the line A-A' drawn in FIG. **3**, and FIG. **4**, (b) is a sectional view along the line B-B' drawn in FIG. **3**.

FIG. **3** shows one CMUT cell. The CMUT cell comprises a lower electrode **202**, a hollow part **204** formed above the lower electrode **202**, projections **206** of an insulating film consisting of a silicon oxide film, formed so as to protrude into the hollow part **204**, an upper electrode **207** formed above the hollow part **204**, and so forth. A wet etching hole **211** for forming the hollow part is communicated with the space serving as the hollow part **204**. An opening **212** is provided so as to reach the lower electrode **202**, and an opening **213** is provided so as to reach the upper electrode **207**. Between the upper electrode **207** and the hollow part **204**, the insulating film **205** consisting of a silicon oxide film is formed so as to cover the hollow part **204** and the lower electrode **202**, and between the lower electrode **202** and the hollow part **204**, the insulating film **203** consisting of a silicon oxide film is formed so as to cover the lower electrode. However, these insulating films are not shown in FIG. **3**, in order to show the hollow part **204** and the lower electrode **202**. An opening **208** is provided in the upper electrode **207** so that the upper electrode **207** does not overlap with the projection **206** as seen from above. By providing the opening in the upper electrode **207**, accumulation of electrical charge in the projection, which consists of the insulating film, can be prevented.

As shown in FIGS. **4**, (a) and (b), the lower electrode **202** of the CMUT is formed on the insulating film **201** consisting of the silicon oxide film and formed on a semiconductor substrate **200**. Above the lower electrode **202**, the hollow part **204** is formed via the insulating film **203** consisting of a silicon oxide film. The insulating film **205** consisting of a silicon oxide film is formed so as to surround the hollow part **204**, and the upper electrode **207** is formed on the insulating film **205**. On the lower surface of the insulating film **205**, the projections **206** consisting of a silicon oxide film are formed so as to protrude into the hollow part **204**, and the openings **208** are formed in the upper electrode **207** above the projection **206**. An insulating film **209** and an insulating film **210** consisting of silicon nitride films are formed on the upper electrode **207**. Further, the wet etching hole **211** is formed in the insulating film **205** and the insulating film **209** so as to penetrate these films. This wet etching hole **211** is formed to produce the hollow part **204**, and it is filled with the insulating film **210** after the formation of the hollow part **204**.

In the CMUT shown in FIGS. **3** and **4**, as seen from above, there are disposed one projection at the center of the membrane, and two projections on each diagonal line of the hexagon starting from the center of the membrane and going toward the edge of the hollow part, and this disposition pattern of the projections is determined by the method explained with reference to FIGS. **5** and **6**.

FIG. **5**, (a) is a sectional view along the line C-C' drawn in FIG. **3**, and shows a state that voltage for driving the CMUT is not applied by an ultrasonic diagnosis apparatus, and the lower electrode **202**, the lower insulating film **203**, the hollow part **204**, the upper insulating film **205**, the projections **206**, and the upper electrode **207** are selectively shown. The projections **206** consisting of the insulating film are numbered **2061**, **2062** and **2063**, respectively, from the center of the membrane (on the side of C of the section along C-C') to the edge of the hollow part (on the side of C' of the section along C-C') as seen from above.

FIG. **5**, (b) shows a state that the projections **2062** and **2063** shown in FIG. **5**, (a) are not disposed, but only the projection **2061** is disposed, and when the CMUT is driven by an ultrasonic diagnostic apparatus, the lower surface of the projection **2061** contacts with the lower surface **214** of the hollow part, and the lower surface **215** of the membrane except for the lower surface of the projection contacts with the lower surface **214** of the hollow part.

The procedure for determining the disposition pattern of the projections shown in FIG. **5**, (a) is as follows.

In this procedure, the driving voltage V0 for CMUT applied by an ultrasonic diagnostic apparatus is compared with the voltage V at which the lower surface of the membrane contacts with the lower surface of the hollow part. The voltage V changes with change of size of the intended membrane, and can be determined by performing simulation using the finite element method (FEM) in the step of designing the CMUT. Alternatively, it may be determined by performing applied voltage-capacitance measurement for a trial product device. The former method is preferred, since the voltage V can be obtained, and the disposition pattern of the projections can be determined in the step of designing.

First, when the driving voltage V0 for CMUT applied by an ultrasonic diagnostic apparatus is equal to or larger than the voltage V1 at which the lower surface **215** of the membrane contacts with the lower surface **214** of the hollow part at the center of the membrane, and thus the lower surface **215** is contacted with the lower surface **214** of the hollow part by applying the driving voltage, the projection **2061** is disposed at the center of the membrane.

Further, as for the membrane supported by the projection **2061** at the center of the membrane and the edge of the hollow part shown in FIG. **5**, (b), when the driving voltage V0 for CMUT applied by an ultrasonic diagnostic apparatus is equal to or larger than the voltage V2 at which the lower surface of the membrane contacts with the lower surface of the hollow part, and thus the lower surface **215** of the membrane is contacted with the lower surface of the hollow part by applying the driving voltage V0, then the projection **2062** is disposed at the contacting part **401**. The disposing position of the projection, that is, the position x at which the lower surface of the membrane extending from the projection **2061** at the center of the membrane contacts with the lower surface of the hollow part, is determined according to which one of spring repulsive force of the membrane and electrostatic attractive force between the electrodes is larger than the other at the position x. The spring repulsive force is determined by spring constant of the membrane and amount of displacement of the membrane at the contacting position, the electrostatic attractive force is determined by electrode area and distance between the electrodes at the position x, and they can be obtained by performing a simulation.

A graph showing the relation of the distance from the projection **2061** at the center to the contacting position **401**, that is, the distance d1 indicating the position at which the second projection **2062** is to be disposed, thickness g of the hollow part, the distance d0 between the center of the membrane and the edge of the hollow part, and length p of the projection obtained by a simulation is shown in FIG. **6**. The horizontal axis of the graph shown in FIG. **6** indicates [length p of the projection]/[thickness g of the hollow part], and the vertical axis indicates [distance d1 indicating the projection disposing position]/[distance d0 from the center to the edge]. The distance d1 indicating the disposing position of the second projection can be determined on the basis of this relation.

In this embodiment 1, provided that the length p of the projection is 80 nm, the thickness g of the hollow part is 200 nm, the distance d0 from the center of the membrane to the edge of the hollow part is 100 μm, for example, d1 is determined to be 40 μm on the basis of the relation shown in FIG. **6**, and the projection **2062** is disposed at a distance of 40 μm from the projection **2061**.

The disposing position of the projection **2063** can also be determined in a similar manner. That is, as for the membrane supported by the projection **2062** and the edge of the hollow part, provided that the lower surface **215** of the membrane is contacted with the lower surface of the hollow part by the driving voltage for the CMUT applied by an ultrasonic diagnostic apparatus, the projection **2063** is disposed at the contacting part. Also in this case, the disposing position can be determined on the basis of the relation shown in FIG. **6**. The distance d0−d1 between the projection **2062** and the edge of the hollow part corresponds to d0 used for determining the distance d1 for disposing the projection **2062**, and d2−d1 corresponds to d1. Specifically, the length p of the projection and the thickness g of the hollow part are the same, that is, they are 80 nm and 200 nm, respectively, d0 is 100 μm, and d1 is 40 μm. Therefore, d0−d1 is 60 μm, and d2−d1 is 24 μm. Accordingly, d2 is 64 μm, and the projection **2063** is disposed at a distance of 64 μm from the projection **2061** at the center of the membrane.

When the projections **2061**, **2062** and **2063** are contacted with the lower surface of the hollow part by the driving voltage for CMUT applied by an ultrasonic diagnostic apparatus, and the lower surface **215** of the membrane at a part between the projections or projection and edge of the hollow part is not contacted with the lower surface **214** of the hollow part, it is not necessary to further dispose projections. However, when the projections **2061**, **2062** and **2063** are contacted with the lower surface of the hollow part by the driving voltage for CMUT applied by an ultrasonic diagnostic apparatus, and the lower surface **215** of the membrane at a part between the projections or projection and edge of the hollow part is further contacted with the lower surface **214** of the hollow part, a further projection can be disposed in a similar manner.

Although the above explanation was made with reference to FIG. **5** showing sections along the line C-C' drawn in FIG. **3**, disposing positions of the projections for the other sections can also be determined in a similar manner. Further, since the hollow part of the CMUT shown in FIG. **3** has a hexagonal shape as seen from above, it has rotational symmetry of 60 degrees with respect to the center, and there may be disposed one projection at the center of the membrane, and two projections on each diagonal line of the hexagon starting from the center of the membrane and going toward the edge of the hollow part.

As described above, this embodiment 1 is characterized in that necessity of disposition of a projection of an insulating film is determined on the basis of comparison of the driving voltage for CMUT applied by an ultrasonic diagnostic apparatus and the voltage at which the lower surface of the membrane contacts with the lower surface of the hollow part, and the disposing positions of the projections are determined on the basis of the relation shown in FIG. **6**.

By using this procedure, the necessary minimum number of the projections to be disposed can be determined. Therefore, even when the electrode is disposed so that it does not overlap with the projections of the insulating film as seen from above (in this embodiment, openings are provided in the upper electrode so that the electrode should not overlap with the projections of the insulating film), undue increase of the driving voltage for CMUT and decrease in receiving sensitivity resulting from unduly small overlapping area of the upper and lower electrodes can be suppressed.

When the disposing positions of the projections are determined on the basis of the relation shown in FIG. **6**, even if the projection do not exactly locate at the positions determined by using the curves shown FIG. **6**, equivalent effect can be obtained if they are disposed at such positions that amount of displacement of the membrane at the position at which the lower surface of the membrane contacts with the lower surface of the hollow part changes by up to −10% compared with that observed at the position determined on the basis of the relation shown in FIG. **6**. Specifically, the range of the distance providing the change of the amount of membrane displacement of up to −10% is 0.8d1 to 1.2d1, wherein d1 is the distance to the contacting position.

Further, when a projection is disposed at a position at which the membrane supported by a projection and the edge of the hollow part contacts with the lower surface of the hollow part, like the projection **2062** or **2063** shown in FIG. **5**, such a projection is preferably disposed at a position closer to the membrane center than the position determined on the basis of the relation shown in FIG. **6** for suppressing contact of the lower surface of the membrane with the lower surface of the hollow part.

Hereafter, another example of the embodiment 1 will be explained with reference to FIGS. **7** and **8**. FIG. **7** is a top view of a CMUT cell, and FIG. **8** shows a section along the line A-A' drawn in FIG. **7**.

As shown in FIG. **7**, the CMUT cell of this example has the hollow part having a rectangular shape as seen from above, and constituted by the lower electrode **202**, the hollow part **204** formed above the lower electrode **202**, the projections **6061**, **6062**, **6063** and **6064** of the insulating film consisting of a silicon oxide film, formed so as to protrude into the hollow part **204**, the upper electrode **207** formed above the hollow part **204**, and so forth. The wet etching hole **211** for forming the hollow part is communicated with the space serving as the hollow part **204**. The opening **212** is provided so as to reach the lower electrode **202**, and the opening **213** is provided so as to reach the upper electrode **207**. Between the upper electrode **207** and the hollow part **204**, the insulating film **205** consisting of a silicon oxide film is formed so as to cover the hollow part **204** and the lower electrode **202**, and between the lower electrode and the hollow part, the insulating film **203** consisting of a silicon oxide film is formed so as to cover the lower electrode. However, these insulating films are not shown in the drawing, in order to show the hollow part **204** and the lower electrode **202**. The openings **208** are provided in the upper electrode **207** so that the upper electrode **207** does not overlap with the projections **6061**, **6062**, **6063** and **6064** as seen from above.

FIG. **8** show a section along the line A-A' drawn in FIG. **7**, and representatively shows the lower electrode **202**, the lower insulating film **203**, the hollow part **204**, the upper insulating film **205**, projections of the insulating film, and the upper electrode **207**. The other configurations are the same as those shown in FIG. **4**. The projections of the insulating film are numbered **6061**, **6062**, **6063** and **6064** from the projection at the center of the membrane (on the side of A of the section along A-A') toward the edge of the hollow part (on the side of A' of the section along A-A') as seen from above.

The procedure for determining the disposing positions of the projections **6061**, **6062**, **6063** and **6064** is the same as the procedure explained with reference to FIGS. **5** and **6**. First, when the lower surface **215** of the membrane at the center of the membrane is contacted with the lower surface **214** of the hollow part by the driving voltage for CMUT applied by an ultrasonic diagnostic apparatus, the projection **6061** is disposed at the center of the membrane.

Further, as for the membrane in which the projection **6061** at the center of the membrane contacts with the lower surface **214** of the hollow part **204**, and thus which is supported by the projection **6061** and the edge of the hollow part, when the lower surface **215** of the membrane except for the lower surface of the projection is contacted with the lower surface **214** of the hollow part by the driving voltage for CMUT applied by an ultrasonic diagnostic apparatus, the projection **6063** is disposed at the contacting part. In this case, the distance from the projection **6061** at the center of the membrane to the contacting position, that is, the distance d1 indicating the position at which the projection **6063** is to be disposed, the thickness g of the hollow part, the distance d0 between the center of the membrane and the edge of the hollow part, and the length p of the projection are in the relation shown in FIG. **6** as in the case explained above, and d1 can be determined on the basis of the relation.

Then, the disposing position of the projection **6064** can also be determined in the same manner. That is, as for the membrane in which the projection **6063** contacts with the lower surface **214** of the hollow part **204**, and thus which is supported by the projection **6063** and the edge of the hollow part, when the lower surface **215** of the membrane is contacted with the lower surface **214** of the hollow part by the driving voltage for CMUT applied by an ultrasonic diagnostic apparatus, the projection **6064** is disposed at the contacting part. Also in this case, the disposing position can be determined on the basis of the relation shown in FIG. **6**.

Further, the disposing position of the projection **6062** can also be determined in the same manner. That is, as for the membrane in which the projections **6061** and **6063** contact with the lower surface of the hollow part, and thus which is supported by the projections **6061** and **6063**, when the lower surface **215** of the membrane is contacted with the lower surface **214** of the hollow part by the driving voltage for CMUT applied by an ultrasonic diagnostic apparatus, the projection **6062** is disposed at the contacting part. In this case, since the projections **6061** and **6063** have the same length, that is, the length p of the projection and the thickness g of hollow part are the same, the lower surface of the membrane contacts with the lower surface of the hollow part at the middle point between the projections **6061** and **6063** according to the relation of FIG. **6**. Therefore, the projection **6062** can be disposed at the middle point between the projections **6061** and **6063**.

FIG. **9** is a flowchart of the aforementioned procedure for determining necessity of disposition of the projection and disposing position thereof. In each step, the driving voltage V0 for CMUT applied by an ultrasonic diagnostic apparatus and the voltage Vi (i=1, 2, 3 . . . k+1, and k is a number of projections to be finally disposed, including the center projection to the end projection) at which the lower surface of the membrane except for the lower surfaces of the projections contacts with the lower surface of the hollow part are compared to determine whether the lower surface of the membrane contacts with the lower surface of the hollow part, and when it is determined that the lower surface of the membrane contacts with the lower surface of the hollow part, a projection is disposed at the contacting point. When a projection is disposed, disposing position of the projection is determined on the basis of the relation shown in FIG. **6**, and projections are further disposed in the same flow of the process, until the lower surface of the membrane is no longer contacted with the lower surface of the hollow part by the driving voltage for CMUT.

In the example shown in FIGS. **7** to **9**, the projections **6061** to **6064** are disposed. However, if the driving voltage for CMUT applied by an ultrasonic diagnostic apparatus may be low, it is not necessary to dispose those projections, that is, no projection may be disposed, only the projection **6061** may be disposed, or only the projections **6061** and **6063** may be disposed. Further, order of determinations of necessities of disposing the projections **6064** and **6062** is also determined according to which one of the voltages which make the lower surface of the membrane contact with the lower surface of the hollow part at the positions where the projections are disposed is larger than the other, and it is apparent that there may be a case where it is necessary to dispose the projection **6062**, but it is not necessary to dispose the projection **6064**.

Moreover, it is of course that, at the time of determining necessity of disposing a projection, it is necessary to take into consideration stability of the driving voltage and variation of the contact voltage of the membrane caused by manufacturing error occurring in the manufacture of CMUTs.

As described above, by comparing the driving voltage for CMUT applied by an ultrasonic diagnostic apparatus and the voltage at which the lower surface of the membrane contacts with the lower surface of the hollow part to determine necessity of disposing a projection of the insulating film, and determining disposing position of the projection on the basis of the relation shown in FIG. **6**, the necessary minimum number of the projections can be disposed. Therefore, even when the electrode is disposed so that it does not overlap with the projections of the insulating film as seen from above, undue increase of the driving voltage for CMUT and decrease in receiving sensitivity resulting from unduly small overlapping area of the upper and lower electrodes can be suppressed.

Although the projections used in the embodiment 1 have such a structure that they protrude into the hollow part from the lower surface of the membrane, the same effect can be obtained with a structure that they protrude from the lower surface of the hollow part, and the projections can be disposed on the basis of the relation shown in FIG. **6** according to the procedure shown in FIG. **9**.

Further, although the projections have the same length within the membrane in the embodiment 1, the amount of deformation of the membrane induced by the driving voltage for CMUT becomes largest at the center of the membrane and decreases as the position becomes closer to the edge of the hollow part, therefore, a short projection may be disposed at the center of the membrane seen from above, and a longer projection may be disposed as the position becomes closer to the edge of the hollow part as shown in FIG. **10**. By using such a disposition pattern, a further larger amplitude of the vibration of the membrane can be used. Also in this case, necessity of disposition of a projection can be judged according to the procedure shown in FIG. **9**, and the disposing position of the projection can be determined on the basis of the relation shown in FIG. **6**.

In the examples explained for the embodiment 1, openings are provided in upper electrode as a structure for avoiding overlapping of the electrode and the projections as seen from above. The same shall apply to the case where openings are provided in the lower electrode at positions overlapping with projections. Also in such a case, necessity of disposition of a projection and disposing position of the projection can be judged and determined according to the same procedure, openings can be provided in the lower electrode provided under the projections, then the openings of the lower electrode can be filled with the insulating film, and then the hollow part, the membrane, and so forth can be formed.

## Embodiment 2

In contrast to the embodiment 1 relating to disposition of projections in a single CMUT cell, the embodiment 2 relates to disposition of projections in a transducer comprising a plurality of CMUT cells disposed in an array.

FIG. **11** shows a part of chip consisting of rectangular CMUT cells disposed in an array. As the CMUT shown in FIG. **3**, each CMUT comprises the lower electrode **2021**, **2022** or **2023**, the hollow part **204** formed above the lower electrode **2021**, **2022** or **2023**, the projections **206** of the insulating film consisting of a silicon oxide film formed so as to protrude into the hollow part **204**, the upper electrode **207** formed above the hollow part **204**, and so forth, and the wet etching hole **211** for forming the hollow part is communicated with the space serving as the hollow part **204**. The opening **212** is provided so as to reach the lower electrode **202**, and the opening **213** is provided so as to reach the upper electrode **207**. Between the upper electrode **207** and the hollow part **204**, the insulating film **205** consisting of a silicon oxide film is formed so as to cover the hollow part **204** and the lower electrode **2021**, **2022** or **2023**, and between the lower electrode **2021**, **2022** or **2023** and the hollow part **204**, the insulating film **203** consisting of a silicon oxide film is formed so as to cover the lower electrode **2021**, **2022** or **2023**. However, these insulating films are not shown in the drawing, in order to show the hollow part **204** and the lower electrode **2021**, **2022** or **2023**. The opening **208** is provided in the upper electrode **207** so that the upper electrode **207** does not overlap with the projection **206** as seen from above. The layer structure of each CMUT cell shown in FIG. **11** for the sectional direction is the same as that shown in FIG. **4**.

In the array, the disposition directions of the upper electrodes and the lower electrodes are perpendicular to each other, two CMUT cells are disposed at one intersection, and the upper electrodes of them are connected with a wiring **1001**. In FIG. **11**, there is shown a part of the array, which comprises the upper electrodes for four channels in the azimuth direction and the lower electrodes for three channels in the elevation direction. As for a probe used for an ultrasonic diagnostic apparatus, in the case of a general linear probe, for example, upper electrodes for 192 channels are disposed.

This embodiment 2 is characterized in that the CMUT cells disposed in the elevation direction above the lower electrodes have different disposition patterns of the projections **206** of the insulating film with respect to each lower electrode, as shown in FIG. **11**.

In the case of a transducer having such a plurality of lower electrodes disposed in the elevation direction as shown in FIG. **11**, a form and intensity of ultrasonic beam transmitted and received at each intersection of the upper electrode and the lower electrode can be controlled by changing the voltage applied to each lower electrode, and thereby improvement in image quality of diagnostic images can be expected. Therefore, the voltage applied to the upper and lower electrodes at the time of driving the CMUT changes according to the voltage applied to each lower electrode, and projections of the insulating film in the CMUT cell can be disposed on each lower electrode according to the magnitude of the applied voltage. Positions at which the projections are disposed and number of projections to be disposed can be determined according to the method for disposing the projections explained for the embodiment 1 described above.

In the transducer shown in FIG. **11**, in order to make the beam width for the elevation direction narrow, a larger voltage is applied to the lower electrode **2022** locating at the center, and a smaller voltage is applied to the lower electrodes **2021** and **2023**. Therefore, seven projections are disposed in each CMUT cell overlapping with the lower electrode **2022**, and five projections are disposed in each CMUT cell overlapping with the lower electrode **2021** or **2023**. With such a configuration, the necessary minimum number of the projections can be disposed, and therefore even when the electrode is disposed so that it does not overlap with the projection of the insulating film as seen from above, decrease in receiving sensitivity resulting from unduly small overlapping area of the upper and lower electrodes can be suppressed.

<Configuration of Ultrasonic Diagnostic Apparatus>

Finally, the configuration of the ultrasonic diagnostic apparatus to which the present invention is applied will be explained with reference to FIG. **12**. FIG. **12** is a configurational diagram of the ultrasonic diagnostic apparatus.

The ultrasonic diagnostic apparatus **1201** consists of an ultrasonic probe **1202**, a transmission and reception separation part **1203**, a transmitting part **1204**, a bias part **1206**, a receiving part **1208**, a phasing addition part **1210**, an image processing part **1212**, a display part **1214**, a control part **1216**, and an operation part **1218**.

The ultrasonic probe **1202** is a device for transmitting and receiving ultrasonic waves to and from a subject by being contacted with the subject, and it is provided with an array of ultrasonic transducer elements on a surface to be contacted with the subject. As the ultrasonic transducers, the ultrasonic transducer of the present invention is employed. An ultrasonic wave is transmitted from the ultrasonic probe **1202** to the subject, and reflected echo signals from the subject are received by the ultrasonic probe **1202**. The transmitting part **1204** and the bias part **1206** are devices for supplying a driving signal to the ultrasonic probe **1202**.

The receiving part **1208** is a device for receiving the reflected echo signals outputted from the ultrasonic probe **1202**. The receiving part **1208** performs processing of the received reflected echo signals such as analog-to-digital conversion.

The transmission and reception separation part **1203** switches and separates transmission and reception, so that a driving signal is sent from the transmitting part **1204** to the ultrasonic probe **1202** at the time of transmission, and a received signal is sent from the ultrasonic probe **1202** to the receiving part **1208** at the time of reception.

The phasing addition part **1210** is a device for performing phasing addition of the received reflected echo signals.

The image processing part **1212** is a device for constituting a diagnostic image (for example, tomogram or blood flow image) on the basis of the reflected echo signals subjected to the phasing addition.

The display part **1214** is a display for displaying the diagnostic image obtained by image processing.

The control part **1216** is a device for controlling the constituent elements mentioned above.

The operation part **1218** is a device for giving directions to the control part **1216**. The operation part **1218** is, for example, an inputting means such as trackball, keyboard and mouse.

The ultrasonic diagnostic apparatus of the present invention is characterized by using an ultrasonic transducer comprising a minimum number of necessary projections optimally disposed between the upper and lower electrodes as an ultrasonic transducer of an ultrasonic probe, and provides effects of preventing decrease in effectual electric field produced by driving voltage, improving transmission and reception sensitivity, and so forth.

## INDUSTRIAL APPLICABILITY

The ultrasonic transducer and ultrasonic diagnostic apparatus of the present invention can be widely used as an apparatus for medical diagnosis or diagnosis of structures.

## DESCRIPTION OF NUMERICAL NOTATIONS

**101**, **202**, **2021**, **2022**, **2023** . . . Lower electrode
**102**, **204** . . . Hollow part
**103**, **201**, **209**, **210** . . . Insulating film
**200** . . . Semiconductor substrate
**203** . . . Lower insulating film
**205** . . . Upper insulating film
**104**, **207** . . . Upper electrode
**105** . . . Membrane
**106** . . . Lower surface of membrane
**107**, **214** . . . Lower surface of hollow part
**108** . . . First projection at the center of membrane
**109** . . . n-th projection of insulating film
**110** . . . (n+2)th projection of insulating film
**111** . . . (n+4)th projection of insulating film
**206**, **2061**, **2062**, **2063**, **6061**, **6062**, **6063**, **6064** . . . Projection of insulating film
**208** . . . Opening of upper electrode
**211** . . . Wet etching hole
**212** . . . Opening reaching lower electrode
**213** . . . Opening reaching upper electrode
**215** . . . Lower surface of membrane except for lower surface of projection
**401** . . . Contacting point of lower surface of membrane and lower surface of hollow part
**1001** . . . Wiring connecting upper electrodes
**1101** . . . CMUT chip
**1201** . . . Ultrasonic diagnostic apparatus
**1202** . . . Ultrasonic probe
**1203** . . . Transmission and reception separation part
**1204** . . . Transmitting part
**1206** . . . Bias part
**1208** . . . Receiving part
**1210** . . . Phasing addition part
**1212** . . . Image processing part
**1214** . . . Display part
**1216** . . . Control part
**1218** . . . Operation part

The invention claimed is:

**1**. An ultrasonic transducer comprising:

a first electrode;

a lower insulating film formed on the first electrode;

an upper insulating film provided so as to form a hollow part above the lower insulating film;

a second electrode formed on the upper insulating film wherein:

the lower insulating film or the upper insulating film has a plurality of projections formed on a side of the hollow part, and

the first electrode or the second electrode has openings formed at positions corresponding to the positions at which the plurality of projections are formed;

a first projection of the plurality of projections is formed on the upper insulating film or the lower insulating film at a position corresponding to at least a center of a membrane comprising the upper insulating film and the second electrode;

a second projection of the plurality of projections is formed between the first projection and an edge of the hollow part; and

a third projection of the plurality of projections is formed between the second projection and the edge of the hollow part; and

provided that the first projection is contacted with the upper insulating film or the lower insulating film, and a part of the membrane on a straight line connecting the first projection and the edge of the hollow part is contacted with the lower insulating film by driving voltage applied to the first electrode and the second electrode, the second projection is formed on the contacting part of the membrane.

2. The ultrasonic transducer according to claim 1, wherein: provided that a part of the membrane on a straight line connecting the second projection and the edge of the hollow part is contacted with the lower insulating film by driving voltage applied to the first electrode and the second electrode, the third projection is formed on the contacting part of the membrane.

3. The ultrasonic transducer according to claim 1, wherein: provided that the membrane is contacted with the lower insulating film between the first projection and the second projection by driving voltage applied to the first electrode and the second electrode, the third projection is formed at the middle point between the first projection and the second projection.

4. The ultrasonic transducer according to claim 1, wherein: ultrasonic transducers are disposed in an array, and the ultrasonic transducers have different disposition patterns of projections.

5. A transducer array comprising a plurality of disposed ultrasonic transducers, wherein each of the ultrasonic transducers is the ultrasonic transducer according to claim 1.

6. The transducer array according to claim 5, wherein: the ultrasonic transducer have different disposition patterns of projections.

7. The transducer array according to claim 6, wherein:
the ultrasonic transducers are disposed along mutually perpendicular two-dimensional directions, and
the ultrasonic transducers disposed along one of the directions have different disposition patterns of projections.

8. An ultrasonic diagnostic apparatus comprising:
an ultrasonic probe for transmitting and receiving ultrasonic waves to or from a subject;
an image processing part for constituting an ultrasonogram on the basis of received ultrasonic signals outputted from the ultrasonic probe; and
a display part for displaying the ultrasonogram;
wherein:
the ultrasonic probe comprises:
an ultrasonic transducer comprising a first electrode,
a lower insulating film formed on the first electrode,
an upper insulating film provided so as to form a hollow part above the lower insulating film, and
a second electrode formed on the upper insulating film,
wherein the lower insulating film or the upper insulating film has a plurality of projections formed on the side of the hollow part, and the first electrode or the second electrode has openings formed at positions corresponding to the positions at which the plurality of projections are formed.

9. The ultrasonic diagnostic apparatus according to claim 8, wherein:
the ultrasonic transducers has a first projection of the plurality of projections formed on the upper insulating film or the lower insulating film at a position corresponding to at least the center of a membrane comprising the upper insulating film and the second electrode.

10. The ultrasonic diagnostic apparatus according to claim 9, wherein:
the ultrasonic transducer has a second projection of the plurality of projections formed between the first projection and an edge of the hollow part; and
provided that the first projection is contacted with the upper insulating film or the lower insulating film, and a part of the membrane on a straight line connecting the first projection and the edge of the hollow part is contacted with the lower insulating film by driving voltage applied to the first electrode and the second electrode, the second projection is formed on the contacting part of the membrane.

11. The ultrasonic diagnostic apparatus according to claim 10, wherein the ultrasonic transducer has a third projection of the plurality of projections formed between the second projection and the edge of the hollow part; and
provided that a part of the membrane on a straight line connecting the second projection and the edge of the hollow part is contacted with the lower insulating film by driving voltage applied to the first electrode and the second electrode, the third projection is formed on the contacting part of the membrane.

12. The ultrasonic diagnostic apparatus according to claim 10, wherein:
the ultrasonic transducer has a third projection of the plurality of projections formed between the second projection and the edge of the hollow part; and
provided that a part of the membrane on the straight line connecting the second projection and the edge of the hollow part is contacted with the lower insulating film by driving voltage applied to the first electrode and the second electrode, the third projection is formed at a position shifted to the first projection side from the contacting part of the membrane.

13. The ultrasonic diagnostic apparatus according to claim 10, wherein:
the ultrasonic transducer has a third projection of the plurality of projections; and
provided that the membrane is contacted with the lower insulating film between the first projection and the second projection by driving voltage applied to the first electrode and the second electrode, the third projection is further formed at the middle point between the first projection and the second projection.

14. The ultrasonic diagnostic apparatus according to claim 8, which uses:
an ultrasonic transducer comprising the ultrasonic transducers disposed in an array, wherein each ultrasonic transducer has different disposition pattern of projections.

15. The ultrasonic transducer according to claim 1, wherein the third projection is a different length from at least one of the first and second projection.

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| 专利名称(译) | 超声换能器和具有该超声换能器的超声诊断设备 | | |
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| 公开(公告)号 | US9085012 | 公开(公告)日 | 2015-07-21 |
| 申请号 | US13/321947 | 申请日 | 2010-05-21 |
| [标]申请(专利权)人(译) | 株式会社日立医药 | | |
| 申请(专利权)人(译) | 日立医疗器械股份有限公司 | | |
| 当前申请(专利权)人(译) | 日立医疗器械股份有限公司 | | |
| [标]发明人 | MACHIDA SHUNTARO<br>KOBAYASHI TAKASHI | | |
| 发明人 | MACHIDA, SHUNTARO<br>KOBAYASHI, TAKASHI | | |
| IPC分类号 | B06B1/02 B81B3/00 H04R19/00 G01N29/24 A61B8/00 | | |
| CPC分类号 | B06B1/0292 B81B3/0021 G01N29/2406 H04R19/005 A61B8/00 A61B8/4483 B81B2201/0257 | | |
| 优先权 | 2009124840 2009-05-25 JP | | |
| 其他公开文献 | US20120069701A1 | | |
| 外部链接 | Espacenet USPTO | | |


摘要(译)

为了在CMUT中设置突出到中空部分中的绝缘膜的突起，以便抑制由于膜的下表面与中空部分的下表面的接触而将电荷注入到绝缘膜中，提供了一种结构，为了抑制CMUT的驱动电压的增加和接收灵敏度的降低，优选配置的突起，以及使用该突起的超声波诊断装置。本发明的超声换能器包括第一电极，形成在第一电极上的下绝缘膜，设置为在下绝缘膜上方形成中空部分的上绝缘膜，以及形成在上绝缘膜上的第二电极并且其特征在于，下绝缘膜或上绝缘膜在中空部分侧具有凸起，并且第一电极或第二电极具有形成在与形成凸起的位置相对应的位置处的开口。