US010342511B2

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

(10) **Patent No.: US 10,342,511 B2**
(45) **Date of Patent: Jul. 9, 2019**

(54) **ULTRASOUND TRANSDUCER ELEMENT AND ULTRASOUND ENDOSCOPE**

(71) Applicant: **OLYMPUS CORPORATION**, Tokyo (JP)

(72) Inventors: **Kazuya Matsumoto**, Nagano (JP); **Katsuhiro Wakabayashi**, Hachioji (JP)

(73) Assignee: **OLYMPUS 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 746 days.

(21) Appl. No.: **14/711,176**

(22) Filed: **May 13, 2015**

(65) **Prior Publication Data**

US 2015/0245811 A1 Sep. 3, 2015

Related U.S. Application Data

(63) Continuation of application No. PCT/JP2013/078935, filed on Oct. 25, 2013.

(30) **Foreign Application Priority Data**

Nov. 15, 2012 (JP) 2012-251444

(51) **Int. Cl.**

A61B 8/00	(2006.01)
A61B 8/12	(2006.01)
B06B 1/02	(2006.01)
H01L 49/02	(2006.01)

(52) **U.S. Cl.**

CPC ***A61B 8/4483*** (2013.01); ***A61B 8/12*** (2013.01); ***B06B 1/0292*** (2013.01); *H01L 28/60* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,262,946 B1	7/2001	Khuri-Yakub et al.	
6,854,338 B2	2/2005	Khuri-Yakub et al.	
2005/0018536 A1 *	1/2005	Caliano	B06B 1/0292 367/7

(Continued)

FOREIGN PATENT DOCUMENTS

EP	1992290 A1	11/2008
JP	2007-229327 A	9/2007

(Continued)

OTHER PUBLICATIONS

Pappalardo et al., "Capacitive Ultrasonic Transducers with a New Vibrating Structrure," Oct. 5, 2003, IEEE Ultrasonics Symposium, pp. 1955-1959.*

(Continued)

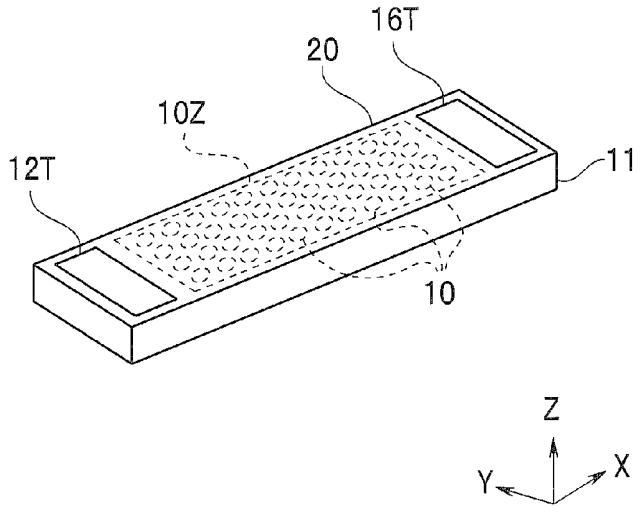
Primary Examiner — Patricia J Park

(74) *Attorney, Agent, or Firm* — Scully, Scott, Murphy & Presser, P.C.

(57) **ABSTRACT**

An ultrasound transducer element including a cell group constituted by a plurality of ultrasound transducer cells, wherein each of the plurality of ultrasound transducer cells includes a lower electrode arranged on a substrate, a membrane including an upper electrode arranged facing the lower electrode with a cavity positioned therebetween, and a plurality of pillars forming the cavity by supporting the membrane, and each cavity mutually communicates with one another.

7 Claims, 13 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

2007/0013269	A1	1/2007	Huang	
2007/0167812	A1*	7/2007	Lemmerhirt	B06B 1/0292 600/459
2008/0089180	A1*	4/2008	Matsumoto	A61B 8/12 367/181
2009/0076393	A1	3/2009	Adachi et al.	

FOREIGN PATENT DOCUMENTS

JP	2008-546239	A	12/2008
JP	2011-035916	A	2/2011
WO	WO 2006/123298	A2	11/2006
WO	WO 2007/099696	A1	9/2007
WO	WO 2010/053032	A1	5/2010

OTHER PUBLICATIONS

International Search Report dated Nov. 26, 2013 issued in PCT/JP2013/078935.

Balasunder, R.I. et al., "Ultrasound Therapy Transducers With Space-Filling Non-Periodic Arrays", IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, May 1, 2011, vol. 58, No. 5, pp. 944-954.

Extended Supplementary European Search Report dated Jul. 6, 2016 in related European Application No. 13 85 4660.1.

* cited by examiner

FIG. 1
PRIOR ART

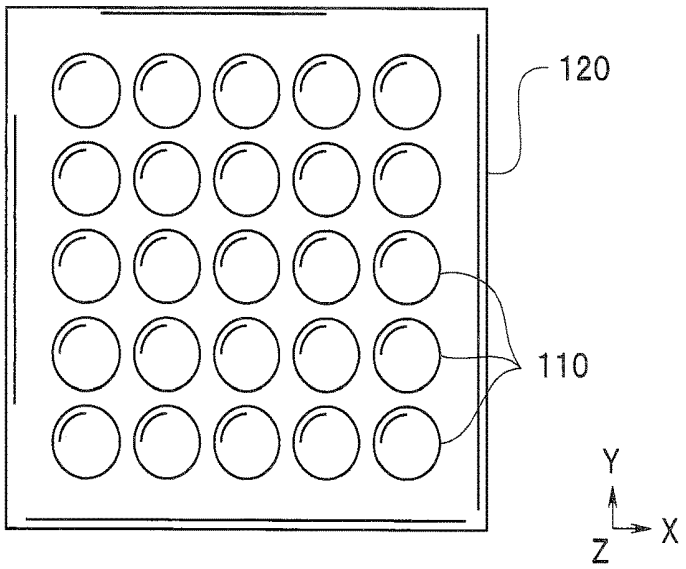


FIG. 2
PRIOR ART

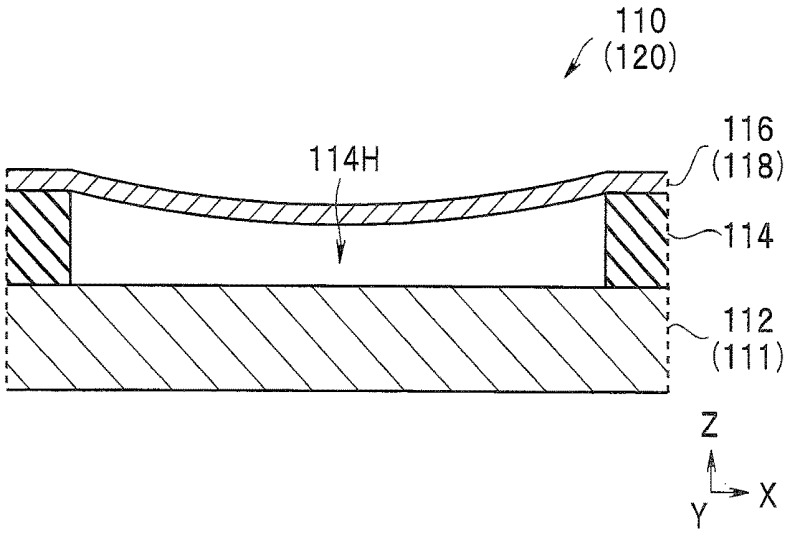


FIG. 3
PRIOR ART

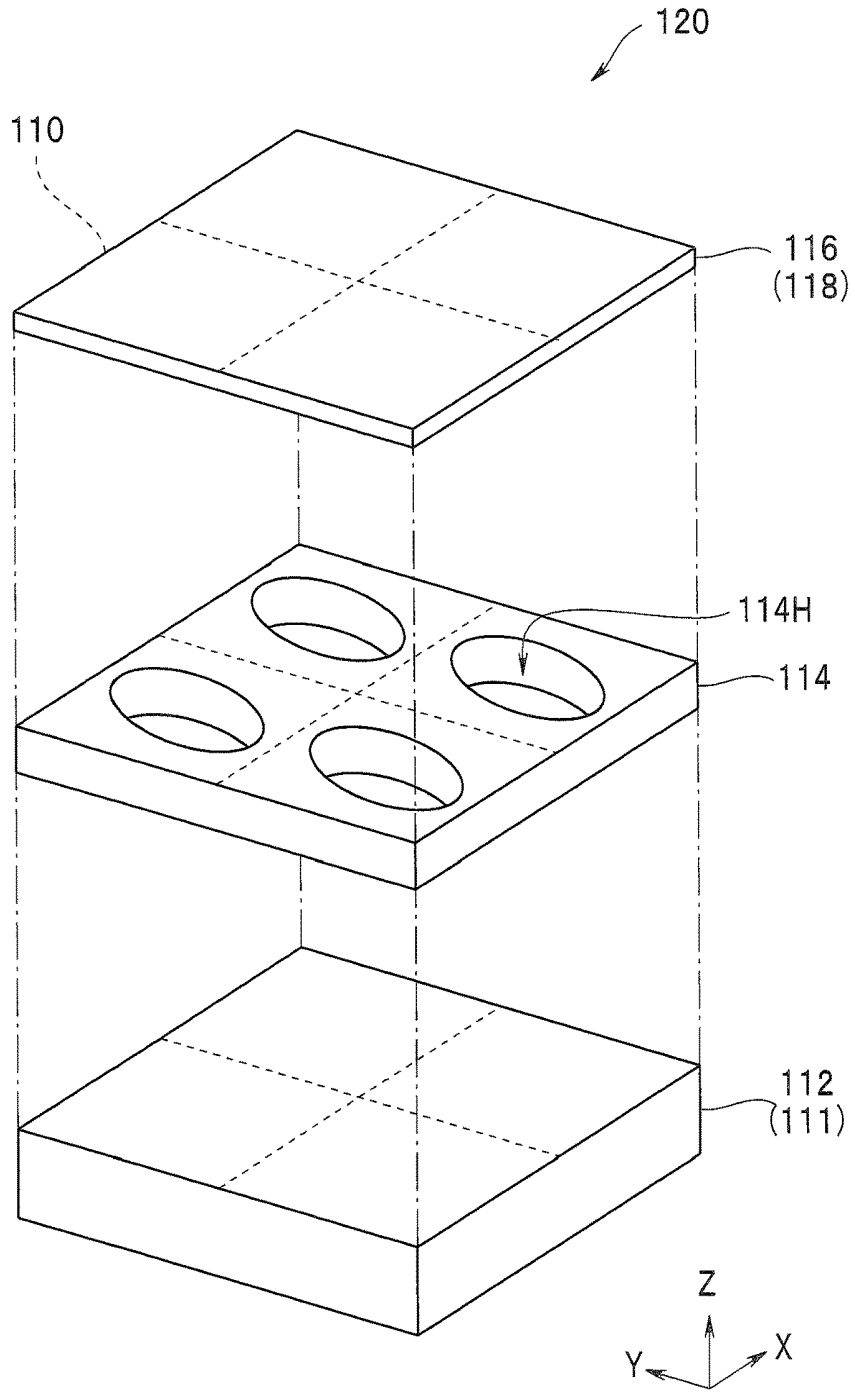


FIG. 4

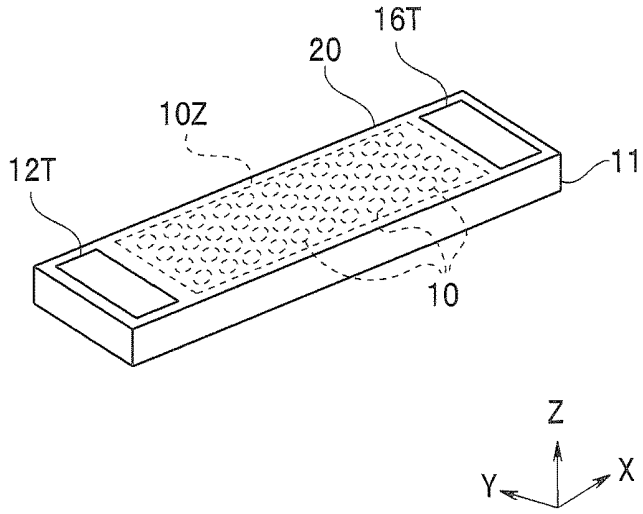


FIG. 5

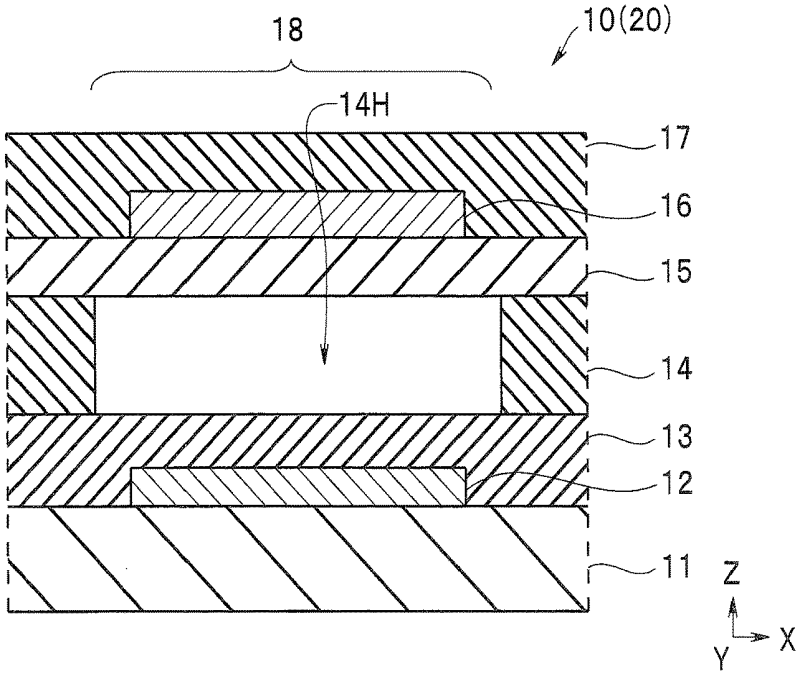


FIG. 6

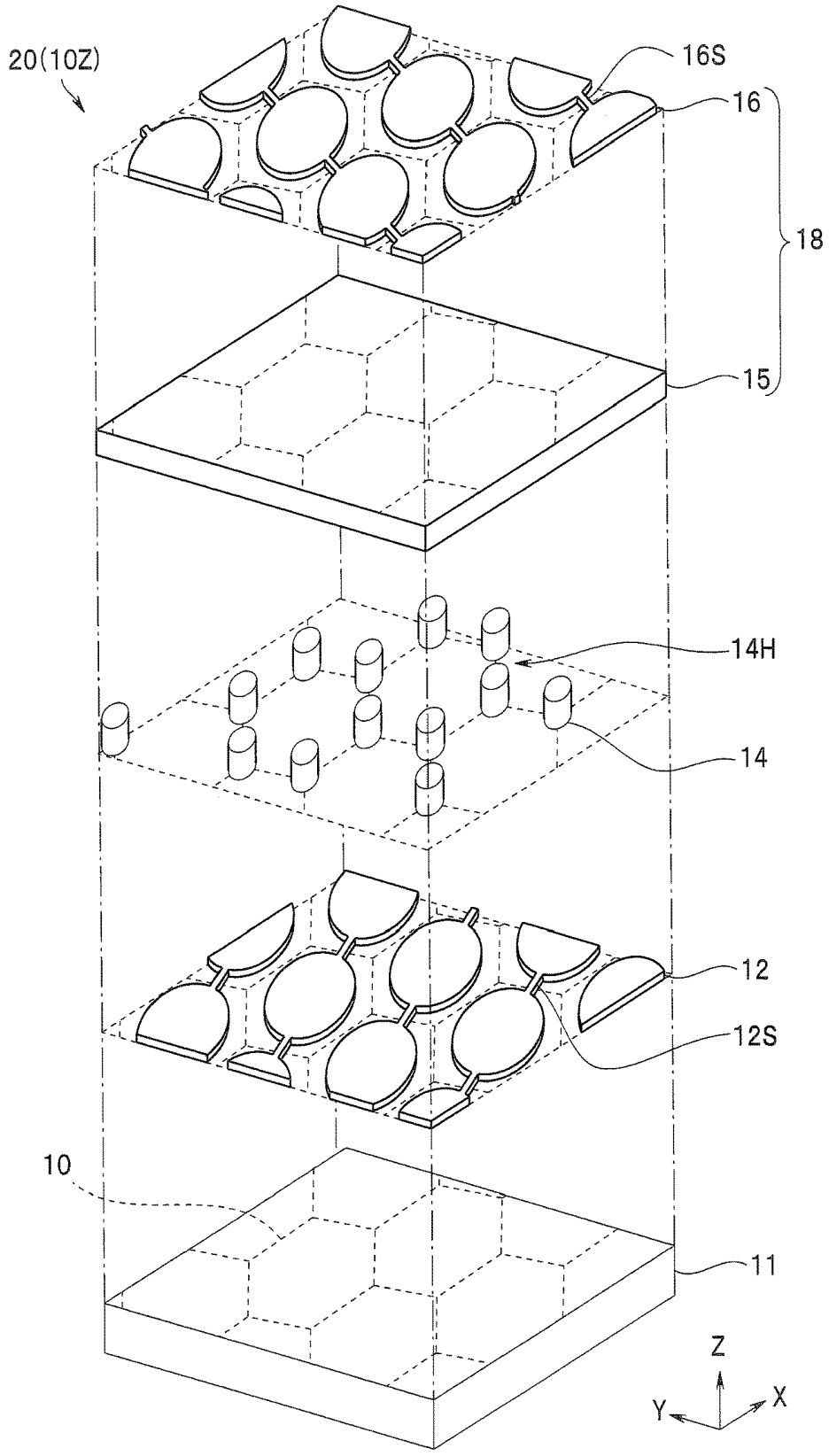


FIG. 7

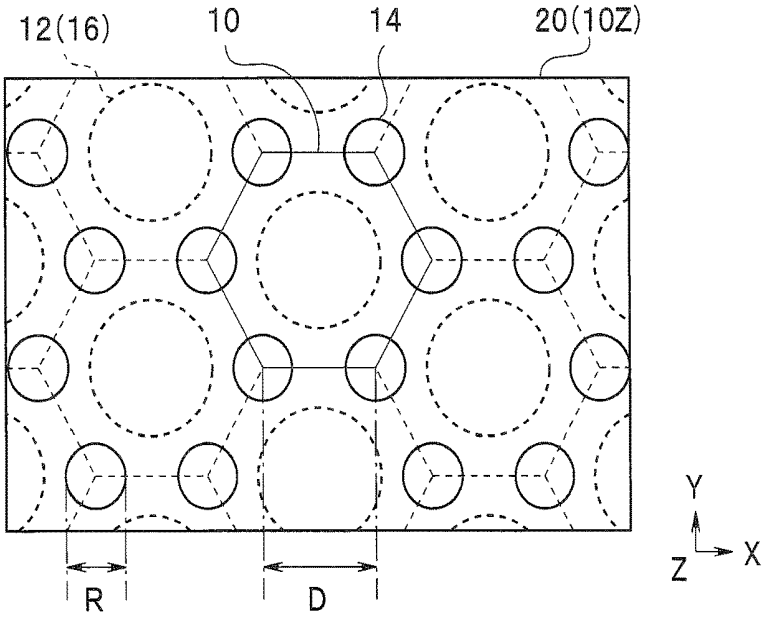


FIG. 8A

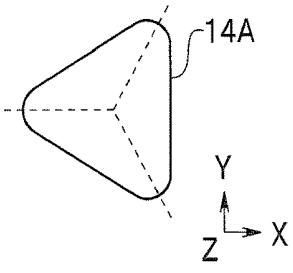


FIG. 8B

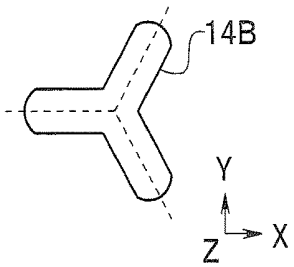


FIG. 8C

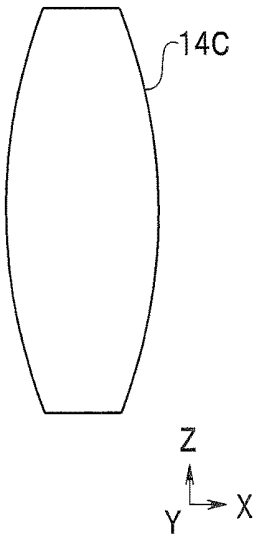


FIG. 8D

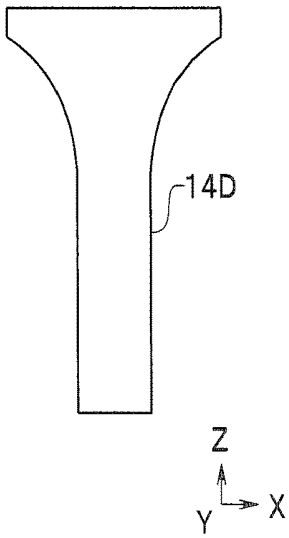


FIG. 9

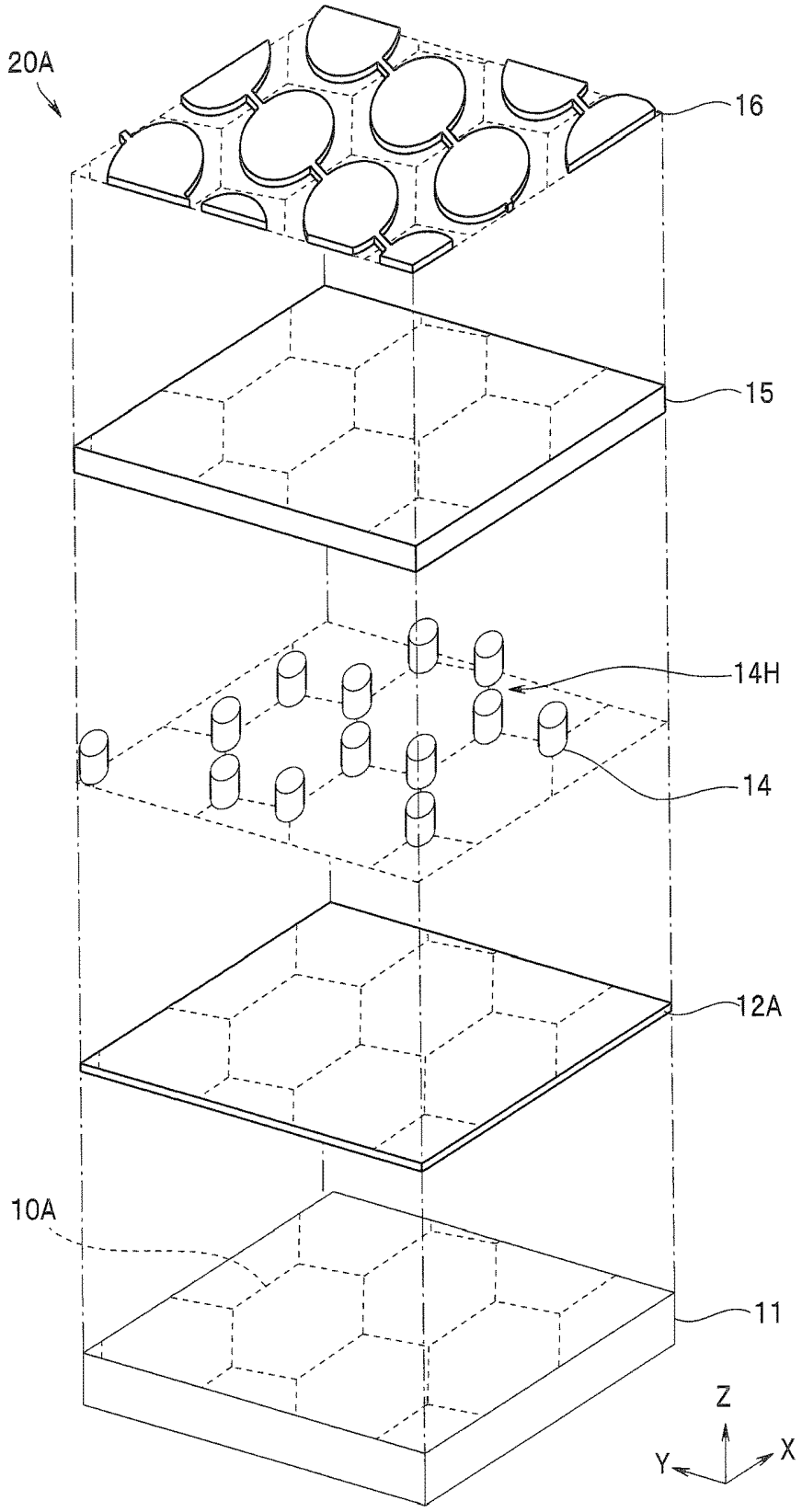


FIG. 10

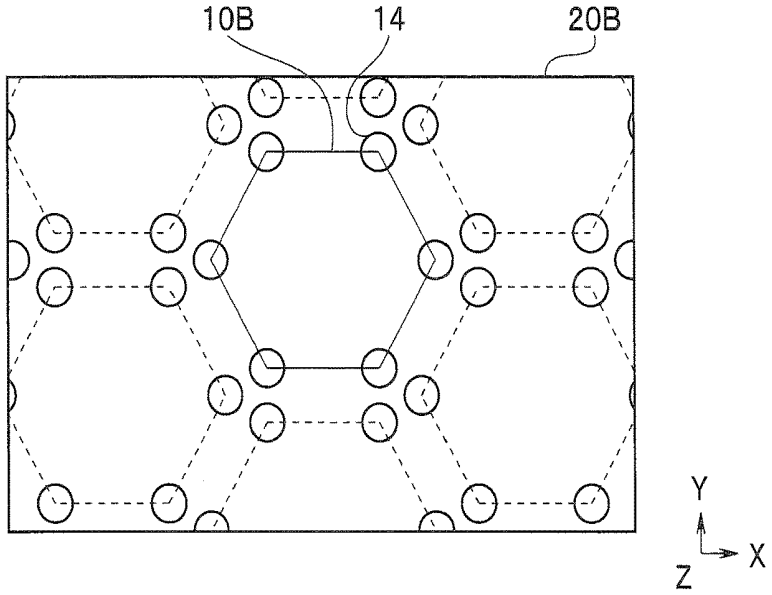


FIG. 11

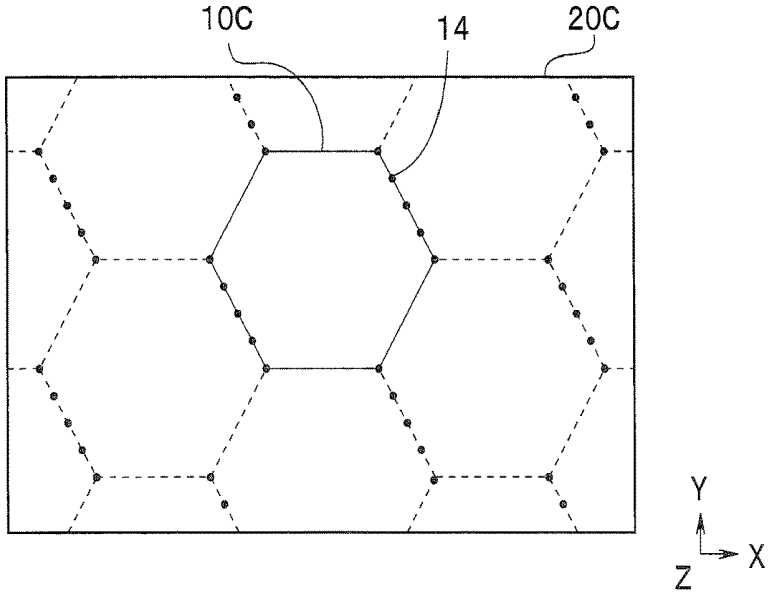


FIG.12

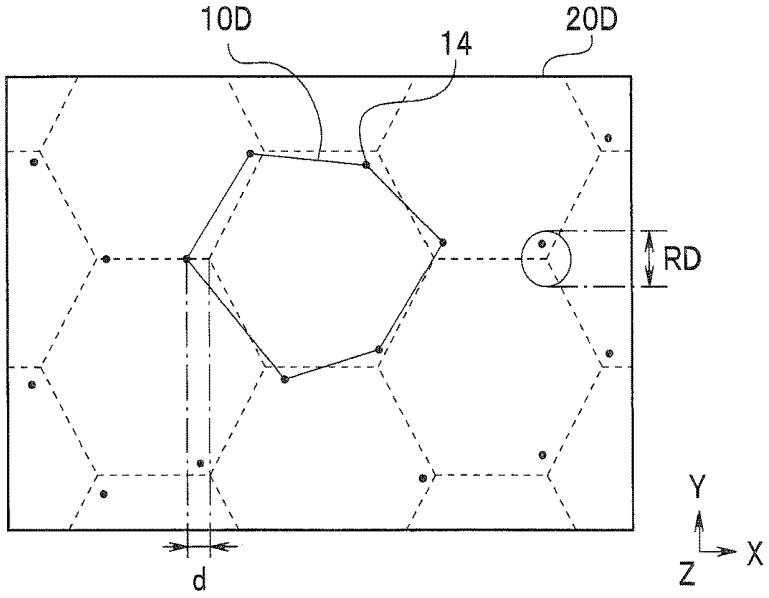


FIG.13

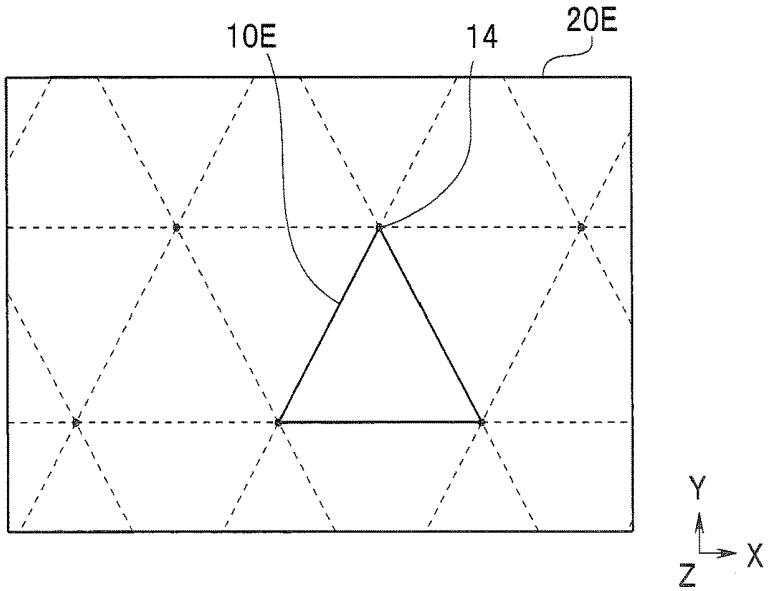


FIG. 14

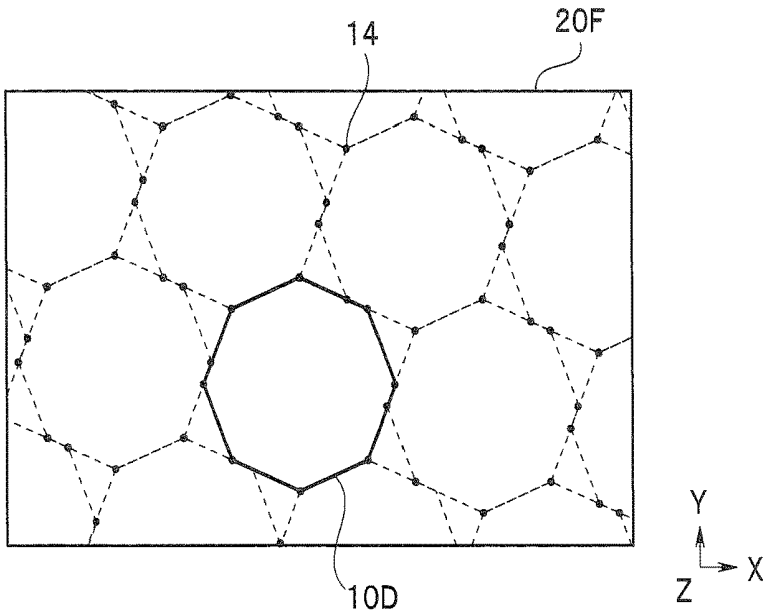


FIG. 15

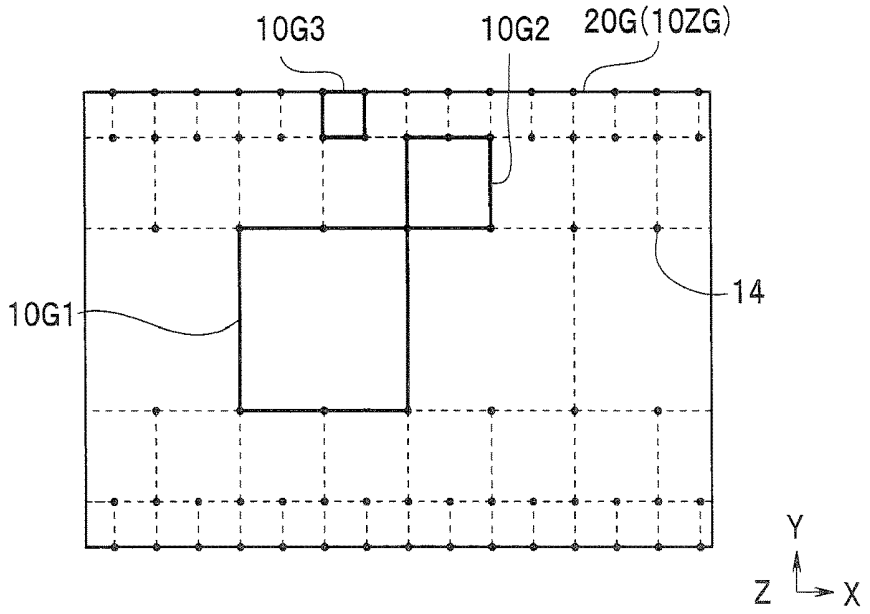


FIG. 16

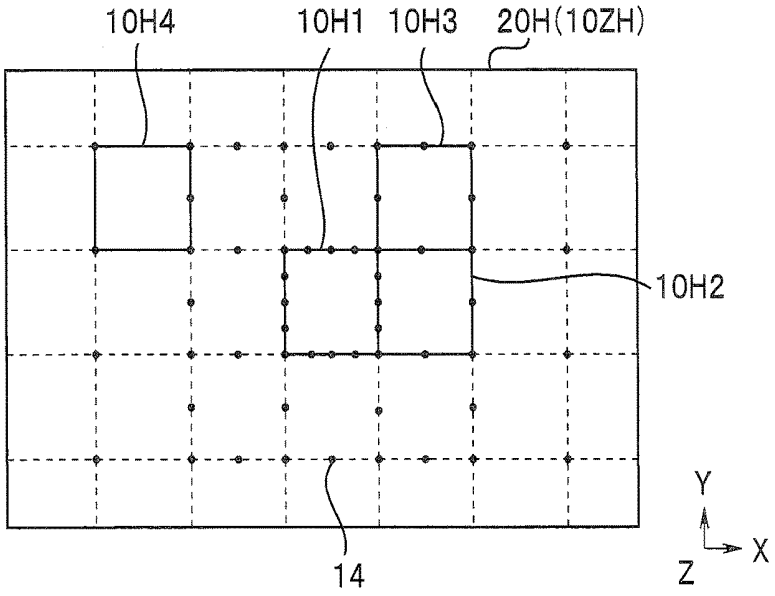


FIG. 17

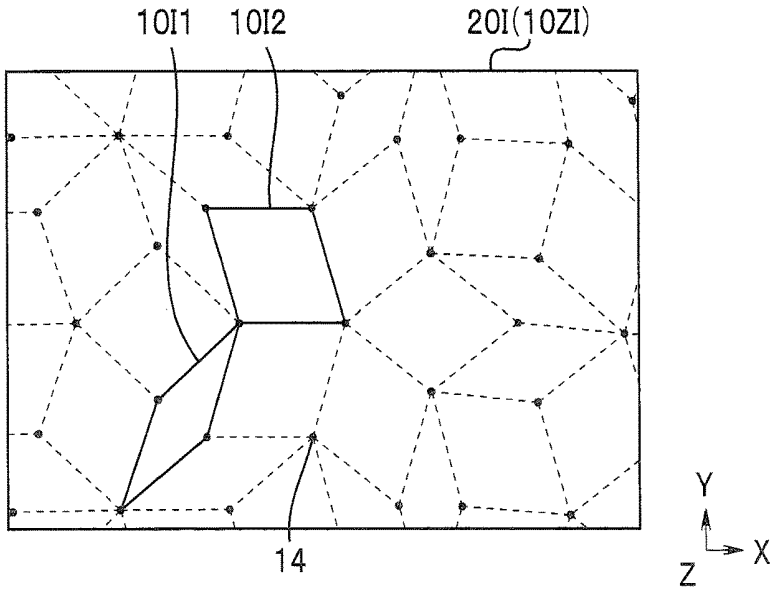


FIG. 18

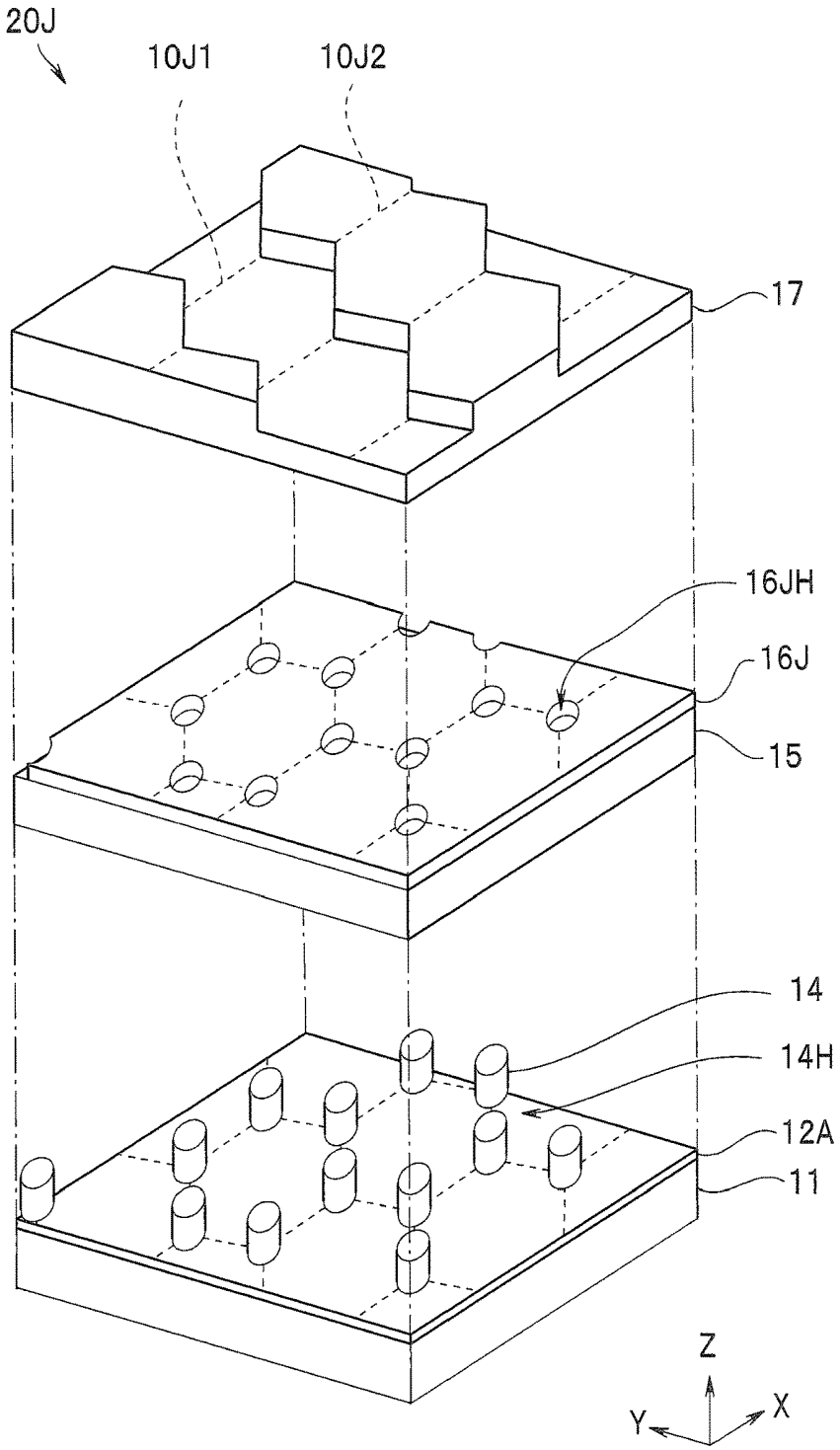


FIG. 19

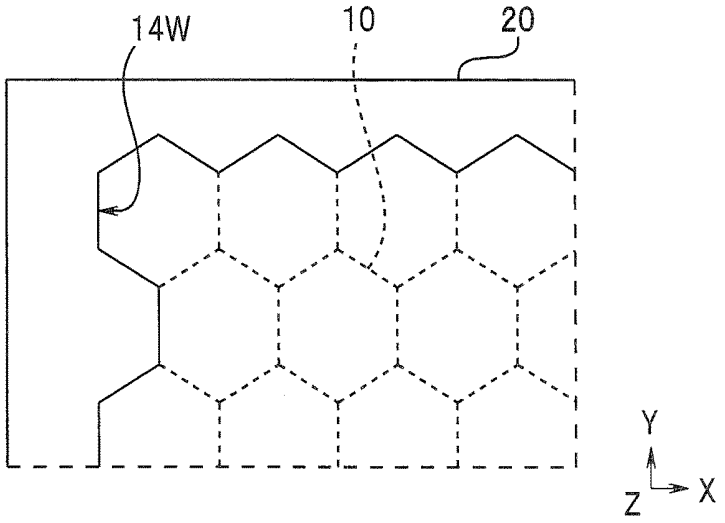


FIG. 20

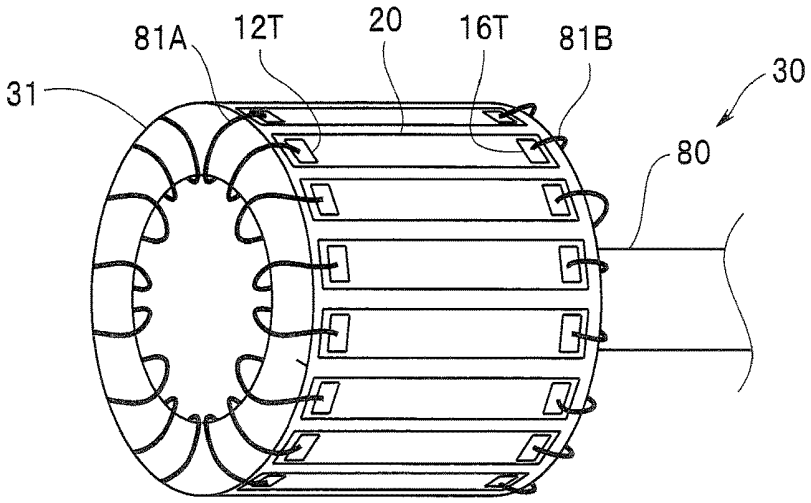
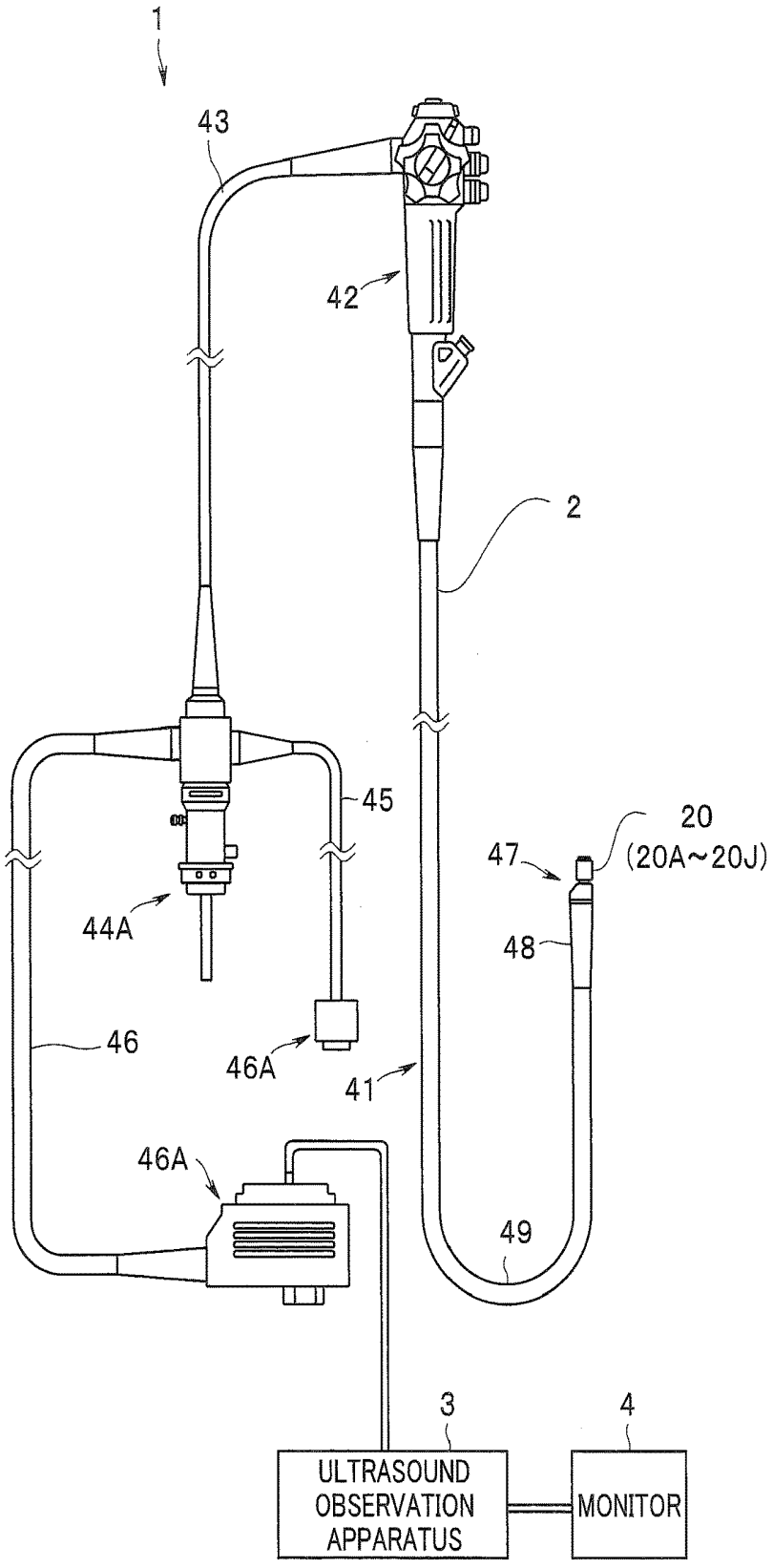


FIG. 21


1
43
42
2
45
20
(20A~20J)
47
48
44A
46
46A
41
46A
49
3
4
ULTRASOUND OBSERVATION APPARATUS
MONITOR

ULTRASOUND TRANSDUCER ELEMENT AND ULTRASOUND ENDOSCOPE

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation application of PCT/JP2013/078935 filed on Oct. 25, 2013 and claims benefit of Japanese Application No. 2012-251444 filed in Japan on Nov. 15, 2012, the entire contents of which are incorporated herein by this reference.

BACKGROUND OF INVENTION

1. Field of the Invention

The present invention relates to an ultrasound transducer element (hereinafter also referred to an "element") provided with a cell group constituted by a plurality of capacitive ultrasound transducer cells (hereinafter also referred to as "cells"), and an ultrasound endoscope provided with an insertion portion with the ultrasound transducer element arranged at a distal end portion.

2. Description of the Related Art

An ultrasound diagnostic method of radiating an ultrasound to an inside of a body and performing imaging of a state inside the body from an echo signal to make a diagnosis has been spreading. One of medical apparatuses used for the ultrasound diagnostic method is an ultrasound endoscope. In the ultrasound endoscope, an element is arranged at a distal-end rigid portion of an insertion portion to be introduced into an inside of a body. The element has a function of converting an electrical signal to an ultrasound and transmitting the ultrasound into the body, and a function of receiving an ultrasound reflected inside the body and converting the ultrasound to an electrical signal.

For a lot of today's elements, ceramic piezoelectric materials including lead, which is environmentally very hazardous, for example, PZT (lead titanium zirconium oxide), are mainly used. On the other hand, development of an element manufactured with the use of MEMS (micro electro mechanical systems) has been advanced, the element having a plurality cells constituted by capacitive micro-machined ultrasonic transducers (hereinafter referred to as "c-MUTs") the material of which does not include lead.

For example, an element **120** shown in FIGS. **1** to **3** is disclosed in specification of U.S. Pat. No. 6,854,338. As shown in FIG. **1**, which is a top view, the element **120** has cells **110** constituted by twenty-five c-MUTs, which are a base unit of ultrasound transmission/reception.

FIG. **2** is a cross-sectional view of one of the cells **110** of the element **120**. FIG. **3** is a partially exploded view of four of the cells **110** of the element **120** shown in FIG. **1**, and a regular square indicated by broken lines shows an area exclusive to one cell **110**, in other words, a plane view shape of the cell **110**. Note that the plane view shape will be hereinafter referred to simply as a shape below. The shape of the cell **110** can be regarded as a regular square.

As shown in FIGS. **2** and **3**, the cell **110** has a conductive substrate **111**, which is also a lower electrode **112**, and an upper electrode **116** arranged facing the substrate **111**, with a cavity **114**H therebetween. An area of the upper electrode **116** immediately above the cavity **114**H constitutes a membrane **118** which ultrasonically vibrates. The cavity **114**H is formed by a through hole formed in an insulating layer **114**. The cavity **114**H is a sealed space isolated from an outside.

When a drive signal is applied between the lower electrodes **112** and the upper electrodes **116**, the membranes **118** vibrate, and the cells **110** generate an ultrasound. When an ultrasound comes in from the outside, the ultrasound is converted to an electrical signal by utilizing a fact that the membranes **118** are deformed, and capacitance between the electrodes changes. The larger an aperture ratio indicated by "(an area of the membranes **118**)/(an area of the cells **110**)", the higher a transmission/reception sensitivity of the element **120** is.

In the element **120** having the regularly square cells **110**, areas other than areas of the membranes **118** immediately above the circular cavities **114**H are non-sensitive areas which do not contribute to transmission/reception of an ultrasound. For example, capacitance between the electrodes in the non-sensitive areas is so-called parasitic capacitance which does not change at a time of receiving an ultrasound.

SUMMARY OF THE INVENTION

An ultrasound transducer element of an embodiment of the present invention is an ultrasound transducer element including a cell group constituted by a plurality of ultrasound transducer cells, wherein each of the plurality of ultrasound transducer cells includes a lower electrode arranged on a substrate, a membrane including an upper electrode arranged facing the lower electrode with a cavity positioned therebetween, and a plurality of pillars forming the cavity by supporting the membrane, and each cavity mutually communicates with one another.

An ultrasound endoscope of another embodiment is an ultrasound endoscope including: an insertion portion with an ultrasound transducer element arranged at a distal end portion thereof, the ultrasound transducer element including a cell group constituted by a plurality of ultrasound transducer cells; an operation portion arranged on a proximal end side of the insertion portion; and a universal cord extending from the operation portion; wherein each of the plurality of ultrasound transducer cells includes a lower electrode arranged on a substrate, a membrane including an upper electrode arranged facing the lower electrode with a cavity positioned therebetween, and a plurality of pillars forming the cavity by supporting the membrane, and each cavity mutually communicates with one another.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top view of a conventional element;

FIG. **2** is a cross-sectional view of an ultrasound transducer cell of the conventional element;

FIG. **3** is an exploded view of the conventional element;

FIG. **4** is a perspective view of an element of a first embodiment;

FIG. **5** is a cross-sectional view of an ultrasound transducer cell of the element of the first embodiment;

FIG. **6** is an exploded view of the element of the first embodiment;

FIG. **7** is a schematic top view for illustrating the cells of the element of the first embodiment;

FIG. **8**A is a diagram showing a modification of a pillar of the element of the first embodiment;

FIG. **8**B is a diagram showing a modification of the pillar of the element of the first embodiment;

FIG. **8**C is a diagram showing a modification of a pillar of the element of the first embodiment;

FIG. **8**D is a diagram showing a modification of a pillar of the element of the first embodiment;

FIG. **9** is an exploded view of an element of a second embodiment;

FIG. **10** is a schematic top view for illustrating an element of a third embodiment;

FIG. **11** is a schematic top view for illustrating an element of a fourth embodiment;

FIG. **12** is a schematic top view for illustrating an element of a fifth embodiment;

FIG. **13** is a schematic top view for illustrating an element of a sixth embodiment;

FIG. **14** is a schematic top view for illustrating an element of a seventh embodiment;

FIG. **15** is a schematic top view for illustrating an element of an eighth embodiment;

FIG. **16** is a schematic top view for illustrating an element of a ninth embodiment;

FIG. **17** is a schematic top view for illustrating an element of a tenth embodiment;

FIG. **18** is an exploded view of an element of an eleventh embodiment;

FIG. **19** is a top view of a sealing wall of the element of the embodiments;

FIG. **20** is a perspective view of an array-type ultrasound transducer of an ultrasound endoscope of a twelfth embodiment; and

FIG. **21** is an external view of the ultrasound endoscope of the twelfth embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

First Embodiment

As shown in FIG. **4**, in an ultrasound transducer element **20** of the present embodiment, a cell group **10**Z constituted by a plurality of ultrasound transducer cells **10** is arranged on a substrate **11**. When a drive signal is applied between a lower electrode terminal **12**T and an upper electrode terminal **16**T, the cell group **10**Z transmits an ultrasound, and the incident ultrasound is converted to an electrical signal on the basis of change in capacitance between the lower electrode terminal **12**T and the upper electrode terminal **16**T, and received.

As shown in FIG. **5**, the cell **10** has a lower electrode **12** connected to the lower electrode terminal **12**T, a lower insulating layer **13** covering the lower electrode **12**, pillars **14** forming a cavity **14**H, and a membrane **18** which is supported by the pillars **14** and includes an upper electrode **16** connected to the upper electrode terminal **16**T. An area of the membrane **18** immediately above the cavity **14**H includes an upper insulating layer **15**, the upper electrode **16**, and a protective layer **17**.

The pillars **14** form the cavity **14**H by supporting the membrane **18**. As described later, the cavity **14**H is a space in a vacuum or a space in which desired gas is sealed at a desired gas pressure.

Note that, though an insulating film is formed on a surface of the substrate **11** made of single crystal silicon or the like, the film is not shown. The lower electrode **12** is a single-layer film or a multi-layer film made of conductive metal, for example, AI, Mo, W, Ti or an alloy of the metals.

Note that graphene, silicene or the like may be used for the upper electrode **16** in order to thin thickness of the membrane **18**. Graphene has a two-dimensional net structure or a structure in which a plurality of two-dimensional net structure layers are laminated, the structure being constituted by carbon atoms. Silicene has a two-dimensional net structure constituted by silicon atoms. Graphene and the like have conductivity, high rigidity and high thermal conductivity equal to those of a metal though its thickness is very small.

The lower insulating layer **13**, the upper insulating layer **15** and the pillars **14** are made of silicon nitride, silicon oxide, tantalum oxide, hafnium oxide or the like. The lower insulating layer **13**, the upper insulating layer **15** and the pillars **14** may be made of different materials, respectively. Note that at least either the lower insulating layer **13** or the upper insulating layer **15** is not an indispensable component.

The lower insulating layer **13** protects the lower electrode **12** during a process and guarantees electrical insulation between the lower electrode **12** and the upper electrode **16**. A surface of the lower insulating layer **13** formed as a film such that it covers the lower electrode **12** is flattened by a CMP method or the like as necessary after being formed as the film.

The cavity **14**H is formed by sacrificing layer etching. That is, the pillars **14** and a sacrificing layer are arranged on the lower insulating layer **13** and covered with the upper insulating layer **15** or the like.

Then, by forming a through hole (VIA hole) in the upper insulating layer **15** or the like covering the sacrificing layer, etchant is injected into the sacrificing layer. Then, by selectively etching the sacrificing layer, the cavity **14**H, which is a cavity portion, is formed. Material of the sacrificing layer is selected from among materials having a high etching selectivity relative to surrounding material. For example, when the lower insulating layer **13** and the like are made of silicon nitride, phosphorus glass or the like is used for the sacrificing layer. The VIA hole is plugged after etching of the sacrificing layer. A hole plugging member may be used as a part of the pillars **14**.

The upper electrode **16** is made of material similar to that of the lower electrode **12**. The protective layer **17** covering the upper electrode **16** is constituted by an insulator made of silicon nitride, silicon oxide, polyimide, polyparaxylylene or the like.

Note that materials of components of the element **20**, a manufacture method of the element **20** and the like are almost the same as those of the conventional element. That is, the element **20** is different from the conventional element in that it is not the insulating layer **114** but the multiple pillars **14** that support the membrane. Therefore, the manufacture method and the like of the element **20** are not limited to the description above, and a well-known element manufacture method and the like can be used.

The cell **10** shown in FIG. **5** appears to resemble the cell **110** shown in FIG. **2**. However, as shown in FIG. **3**, each cavity **114**H is a sealed space in the conventional element **120**. In other words, each cavity **114**H is isolated. In comparison, the cavity **14**H is formed by the plurality of pillars **14** in the element **20** as shown in FIG. **6**. Therefore, the plurality of cavities **14**H of the cell group **10**Z are so-called open cavities which communicate with one another. In other words, the plurality of cavities **14**H form one space.

Note that the lower insulating layer **13** and the protective layer **17** are not shown in the exploded view of FIG. **6**. Further, the top view of FIG. **7** shows only arrangement of the pillars **14**, the lower electrodes **12** and the upper electrodes **16**. Each regular hexagon shown by a broken line in FIGS. **6** and **7** indicates an area exclusive to one cell **10**, in other words, a plane view shape of the cell **10**. Actually, however, borders are not clearly shown. For example, borderlines of the cavities **14**H of the plurality of cells **10** shown by broken lines are virtual lines which do not actually exist.

As shown in FIGS. **6** and **7**, the plurality of cells **10** each of which has a regularly hexagonal plane view shape are closely arranged in the element **20**. That is, each pillar **14** supports the membranes **18** of three adjoining cells **10**, and thereby the cavities **14**H are formed. An area where the upper insulating layer **15** is joined to the pillar **14** is a non-sensitive area which does not vibrate and does not contribute to transmission/reception. However, an aperture ratio of area of a vibration area of the membrane **18** relative to area of the cell in the element **20** is much higher than that of the conventional element. That is, the shape and area of the cell **10** are almost equal to the shape and area of the cavity **14**H.

Note that, strictly, the shape of the cell **10** and the shape of the cavity **14**H excluding the areas of the pillars **14** are different from each other in the element **20** also, but the shape of the cavity **14**H may be hereinafter referred to as the shape of the cell **10**.

The lower electrodes **12** of the plurality of cells **10** are connected with one another via lower electrode wiring **12**S, and the upper electrodes **16** are connected with one another via upper electrode wiring **16**S. That is, the plurality of cells **10** of the element **20** constitute the cell group **10**Z the cells of which are simultaneously driven.

When electric potential that is not zero is applied between the lower electrodes **12** and the upper electrodes **16** via the lower electrode terminal **12**T and the upper electrode terminal **16**T, the membranes **18** are drawn to a direction of the lower electrodes **12** by electrostatic attraction generated by potential difference and displaced. Note that it is preferable from a viewpoint of ensuring safety that potential of the upper electrodes **16** be ground potential.

Displacement of the membrane **18** is maximized at a central point of the cell **10**, and, on borders with adjoining cells, is the largest at a bisection point of each side of the regular hexagon. Further, the displacement is in a line symmetry, with borderlines with the adjoining cells **10** indicated by broken lines as axes. Further, since the cell **10** is a regular hexagon, the displacement is in a six-fold symmetry in which the displacement becomes equal when rotated by sixty degrees relative to the central point of the cell **10**.

When the applied potential is cut off in a state that the membranes **18** are displaced, electrostatic attraction disappears. The membranes **18** vibrate at a resonance frequency determined by constituent material and a structure parameter, and an ultrasound with a number of vibrations equal to the resonance frequency is transmitted.

Note that it is preferable to, in a case of transmitting an ultrasound like a pulse, control a waveform and the like of a drive signal to be applied. For example, it is preferable to, in order to enable displacement of the membranes **18** to follow increase of the applied potential, increase the potential slowly or apply a next pulse after a sufficient time period so that the membranes **18** completely stop vibration. Further, after transmission of the ultrasound, the membranes **18** may be forcedly caused to stop vibration by attraction by application of an auxiliary pulse or by generation of counter vibration by application of an auxiliary pulse with a phase opposite to that of a main pulse.

On the other hand, in a case of successively transmitting ultrasounds for Doppler measurement or the like, a drive signal with a frequency equal to the resonance frequency of the membranes **18**, for example, a drive signal constituted by a triangular wave pulse is applied.

A vibration frequency of the membranes **18** at a time of occurrence of an ultrasound, that is, a frequency of the generated ultrasound is slightly lower than a frequency of an ultrasound generated by cells each of which has a circular cavity inscribed in the regularly hexagonal cell **10**. In order to realize an ultrasound frequency equal to that of the cells having the inscribed circular cavities, the cell **10** can be reduced in a similar shape.

When an ultrasound enters the cells **10**, the membranes **18** vibrate at a frequency of the incident ultrasound by sound pressure of the ultrasound. In response to the vibration, thickness of the cavities **14**H, that is, a distance between the electrodes changes, and the capacitance between the electrodes changes in response thereto. Therefore, by detecting the capacitance between the electrodes, an intensity and frequency of the incident ultrasound are detected.

Note that, by continuously keeping the membranes **18** infinitesimally deformed using a DC offset/bias method in which potential difference is continuously applied between electrodes, the element **20** can transmit and receive an ultrasound with a higher frequency.

Note that the drive signal may be supplied from an outside of the element **20**, or a drive circuit constituted by an IC or the like may be arranged on a back of the element **20**.

Here, it is preferable that a diameter R of a section of the pillar **14**, which is a cylinder, be between 1/20 and 1/5 of a distance D between pillars **14**, inclusive, as shown in FIG. **7**. If the diameter R is within the range or larger, it is possible to stably support the membranes **18**. If the diameter R is within the range or smaller, the aperture ratio is large, for example, 95% or above, and, therefore, the transmission/reception sensitivity is high.

For example, in a case where the distance D and the diameter R are 100 μm and 10 μm in the regularly hexagonal cell **10**, respectively, area of the cell **10** is 26000 μm2, and area of the pillar **14** is 157 μm2. Therefore, the aperture ratio is (26000−157)/26000=99.4%.

In comparison, in the conventional element in which cells are arrayed in a square lattice, each of the cells having an isolated circular cavity, the aperture ratio is "(area of circle)/(area of square circumscribed in the circle)" and, therefore, 78.5% even in a case where the cavities are virtually adjoin one another.

That is, though the aperture ratio is below 80% in the conventional element in which cells are arrayed in a square lattice, each of the cells having an isolated circular cavity, it is possible to easily realize a high aperture ratio exceeding 95% in the element **20**.

Improvement of the ultrasound transmission/reception sensitivity of the element **20** is achieved, and, further expansion of application/development becomes possible. That the aperture ratio is large means that efficient driving of the membranes is possible or that a parasitic capacitance ratio decreases, and a signal-to-noise ratio (SN ratio) increases.

That is, the aperture ratio of the element **20** is large, and its transmission/reception sensitive is high.

Furthermore, in the element **20**, all areas where the lower electrode **12** and the upper electrode **16** face each other contribute to reception of an ultrasound, and the reception sensitivity is high because of not being influenced by parasitic capacitance by a non-sensitive area.

Note that a shape of the pillar **14** is not limited to a cylinder. For example, a section of a pillar **14**A shown in FIG. **8**A is not circular but almost regularly triangular. A pillar **14**B shown in FIG. **8**B is almost star-shaped, with its crosses projecting in three directions. Further, a pillar **14**C shown in FIG. **8**C is in an entasis shape with its central part

expanded, and a pillar **14**D shown in FIG. **8**D is in a decorated pillar shape, with its upper part expanded.

The pillar **14** may be in a shape such as an elliptic cylinder, a polygonal column, a star-shape column, a cone or a polygonal pyramid. Further, the plurality of pillars **14** of the element **20** may be constituted by a plurality of pillars in different shapes. Note that it is preferable that the pillars **45** be designed so that the aperture ratio of the cells is 90% or higher, preferably 95% or higher even in a case of the pillars **45** in a shape other than a cylinder.

Second Embodiment

Since an element **20**A of a second embodiment shown in FIG. **9** resembles the element **20**, same components are given same reference numerals, and description thereof will be omitted.

In the element **20**A, lower electrodes **12**A are lower electrodes common to a plurality of cells **10**A, which is arranged on a whole surface of an area where a cell group **10**ZA is formed. That is, though the lower electrodes **12**A of the respective cells **10**A are shown by broken lines in FIG. **9**, the border lines are virtual lines.

In the element **20**A, the lower electrodes **12**A are arranged on the whole surface. However, since all areas where the upper and lower electrodes face each other are included in the membranes **18**, it does not happen that a non-sensitive area increases in comparison with the element **20** having the patterned lower electrodes **12**.

Since it is not necessary to perform patterning of the lower electrodes **12**A, the element **20**A is easy to manufacture. Further, as already described, since unevenness is formed on the surface of the lower insulating layer **13** formed on the patterned lower electrodes **12** as a film, it is preferable to flatten the surface. In the element **20**A, however, since the lower electrodes **12**A are arranged on the whole surface of the area where the cell group **10**ZA is formed, unevenness is not formed on the surface of the lower insulating layer **13**, and it is unnecessary to perform flattening.

The element **20**A has effects of the element **20**. Further, the element **20**A is easy to manufacture.

Note that it goes without saying that, even if at least either the lower electrodes **12** or the upper electrodes **16** are arranged on the whole surface of the area of the substrate **11** where the cell group **10**Z is faulted, effects similar of those of the element **20**A are provided.

Third Embodiment

Since an element **20**B of a third embodiment shown in FIG. **10** resembles the element **20** and the like, the same components are given the same reference numerals, and description thereof will be omitted.

In the element **20**B, each cell **10**B exclusively has six pillars **14**. Therefore, useless areas which do not contribute to transmission/reception are formed among the cells **10**B.

In the element **20** and the like in which adjoining cells **10** share a pillar **14**, when one pillar is faulty, three cells **10** sharing the pillar become faulty. In comparison, in the element **20**B, even if a pillar is in a bad condition, only one cell **10**B becomes faulty. Therefore, a probability that the element **20**B can be used as a product is high. That is, in the element **20**B, there are a lot of cases where all the cells **10**B are not necessarily required to be good items.

The element **20**B has the effects of the element **20** and the like. Further, manufacturing yield of the element **20**B is higher than that of the element **20** and the like.

Note that it is preferable that the aperture ratio be 90% or above in the element **20**B also. Especially preferably, the element **20**B may be designed so that the aperture ratio becomes 95%. Further, a part of the pillars may be shared by adjoining cells, with remaining pillars being exclusively possessed.

Fourth Embodiment

Since an element **20**C of a fourth embodiment shown in FIG. **11** resembles the element **20** and the like, the same components are given the same reference numerals, and description thereof will be omitted. Note that, in the figure below, the pillars **14** are indicated by black circles indicating centers of the pillars **14**.

In the element **20**C, pillars **14** are arranged not only at six apexes of each regularly hexagonal cell **10**C. Three pillars **14** are also arranged on each of two sides, which are borderlines with adjoining cells. That is, the membrane of the cell **10**C is supported by twelve pillars **14**.

Displacement of the membrane of the cell **10**C is not in a six-fold symmetry relative to a center of the cell but in a two-fold symmetry, and the membrane is displaced in a complicated shape. Therefore, in the cell **10**C, a width of a resonance frequency is wide.

The element **20**C has the effects of the element **20**. Further, an ultrasound generated by the membranes **18** is a wide-band ultrasound, and, similarly, transmission/reception of a wide-band ultrasound is possible.

Fifth Embodiment

Since an element **20**D of a fifth embodiment shown in FIG. **12** resembles the element **20** and the like, the same components are given the same reference numerals, and description thereof will be omitted.

In the element **20**D, the pillars **14** are arranged not at apexes of regularly hexagonal cells **10**D but at positions slightly deviated from the apexes. Though an amount of deviation d is set at random, the pillars **14** are set inside a circle with a diameter RD. It is preferable that the diameter RD be between 1/100 and 1/10 of the distance D, inclusive. Effects are remarkable within the above range. The amount of deviation d is set, for example, on the basis of a random number.

In a cell **10** in which the distances D among pillars **14** are the same, there is a possibility that unnecessary resonance occurs, or an unnecessary transverse wave occurs. In comparison, in the element **20**D, since pillars **14** of each cell **10**D are arranged at random with a slight planar displacement from apexes of a regular hexagon, the possibility that unnecessary resonance occurs does not exist.

That is, the element **20**D has the effects of the element **20**. Further, the possibility that unnecessary resonance occurs does not exist.

Sixth and Seventh Embodiments

Since an element **20**E of a sixth embodiment and an element **20**F of a seventh embodiment resemble the element **20** and the like, the same components are given the same reference numerals, and description thereof will be omitted.

As shown in FIG. **13**, regularly triangular cells **10**E are closely arranged in the element **20**E. That is, the membrane **18** of each cell **10**E is supported by three common pillars **14**. Further, as shown in FIG. **14**, each cell **10**F is regularly octagonal in the element **20**F. The membrane **18** of each cell

10F is supported by twelve pillars **14**, and eight among the twelve pillars are arranged at apexes of the regularly octagonal cell **10**F.

The element **20**E and the element **2**OF have the same effects as the element **20**. That is, if such transducer cells are provided that the cavities **14**H are formed by the pillars **14** supporting the membranes **18**, a number of the pillars supporting each transducer cell is not limited to six as long as it is three or larger. Note that it is preferable that the number of the pillars supporting each transducer cell be sixteen or fewer, and it is easy to increase the aperture ratio if the number is within the range or fewer.

A plane view shape of the membrane (cell) is not limited to a particular shape. For example, the plane view shape may be a parallelogram, a rectangle, a diamond shape or a trapezoid. Especially, a shape which enables a plurality of cells to be planarly filled, that is, which enables a plurality of cells to be closely arranged is favorable because it is easy to increase the aperture ratio.

Eighth to Eleventh Embodiments

Since an element **20**G of an eighth embodiment to an element **20**J of an eleventh embodiment resemble the element **20** and the like, the same components are given the same reference numerals, and description thereof will be omitted.

As shown in FIG. **15**, a cell group **10**ZG of the element **20**G of the eighth embodiment is provided with three kinds of cells **10**G**1** to **10**G**3** having cavities in the same regularly square shape but having different sizes (plane view dimensions of the cells **10**G).

As shown in FIG. **16**, a cell group **10**ZH of the element **20**H of the ninth embodiment is provided with four kinds of cells **10**H**1** to **10**H**4** having cavities in the same shape and with the same size but being different in a number of pillars **14** supporting each cavity.

As shown in FIG. **17**, a cell group **10**ZI of the element **20**I of the tenth embodiment is provided with two kinds of cells **10**I**1** and **10**I**2** which are different in the shape of the cavities (cells).

As shown in FIG. **18**, a cell group **10**ZJ of the element **20**J of the eleventh embodiment is provided with two kinds of cells **10**J**1** and **10**J**2** having the same cavity shape and the like but being different in thickness of the membranes **18**.

In a cell group, a plurality of kinds of cells that are different in at least any that is selected from among the plane view shape of the cavities, the size of the cavities (plane view dimension), the number of pillars, and the thickness of the membranes are different in the resonance frequency.

Therefore, a frequency band of an ultrasound which can be transmitted or received by the elements **20**G to **20**J is wide. For example, in the element **20**G shown in FIG. **15**, the largest cell **10**G**1** is arranged in a central part of the element **20**G, and the smallest cell **10**G**3** is arranged on an outermost periphery. Since the frequency of an ultrasound generated by the large cell **10**G**1** is low, a beam easily spreads. Since the frequency of an ultrasound generated by the small cell **10**G**3** is high, a beam does not easily spread. In the element **20**G, since the low-frequency cells are arranged in the central part, convergence of an ultrasound beam in the whole element is good.

On the other hand, in the element **20**H shown in FIG. **16**, since the membrane **18** of the cell **10**H**1** arranged in a central part is supported by sixteen pillars **14**, a resonance frequency is high. In comparison, since the membrane **18** of the cell **10**H**4** arranged in a surrounding area is supported by five pillars **14**, a resonance frequency is low. The membrane **18** of the cell **10**H**2** arranged between the cell **10**H**1** and the cell **10**H**3** is supported by ten pillars **14**, and the membrane **18** of the cell **10**H**3** is supported by eight pillars **14**. Therefore, resonance frequencies of the cell **10**H**2** and the cell **10**H**3** are between the resonance frequency of the cell **10**H**1** and the resonance frequency of the cell **10**H**4**.

In the element **20**H, observation with high resolution is possible on a near-point side of an observation target. That is, high resolution is possible on the near-point side because an image is formed by a high-frequency signal there.

Shapes of the two kinds of cells **10**I**1** and **1012** of the element **20**I shown in FIG. **17** are two kinds of diamond shapes constituting a Penrose tile pattern, and pillars are arranged at apexes of the two kinds of diamond shapes. In a Penrose tile pattern, two kinds of diamond shapes (a diamond shape with an acute angle of 72 degrees and an obtuse angle of 108 degrees, and a diamond shape with an acute angle of 36 degrees and an obtuse angle of 144 degrees) are planarly filled. In a case of filling using regular polygons, a periodic pattern appears. In the Penrose pattern, however, a periodic pattern does not appear unlike other plane filling.

Since the Penrose tile pattern has a specific symmetry of a five-fold symmetry, it does not have a translational symmetry when seen planarly. Therefore, unnecessary resonance seldom occurs in the element **20**I, and the element **20**I can be especially preferably used.

Note that, since a diamond-shaped cell shows a resonance frequency equal to that of a cell having an elliptical cavity of an almost same size, the element **20**I has two kinds of resonance frequencies. Furthermore, an element having a plurality of cells obtained by reducing or expanding a Penrose tile pattern in one direction is a wide-band element which theoretically has ten kinds of resonance frequencies.

In the element **20**J shown in FIG. **18**, a resonance frequency of the cell **10**J**2** the membrane **18** of which has a larger thickness is higher than a resonance frequency of the cell **10**J**1** the membrane **18** of which has a smaller thickness. That is, a resonance frequency is in proportion to thickness of a membrane.

Note that arrangement of cells in an element having a plurality of kinds of cells which are different in the resonance frequency can be changed according to purposes. Further, a number of the kinds of cells may be two or more.

All of the elements **20**G to **20**J have the effects of the element **20** and the like and, further, have a wider-band characteristics. Therefore, the elements **20**G to **20**J can be applied to ultrasound Doppler measurement and the like. Further, arrangement of cells in consideration of directivity of a sound wave in an element, arrangement of cells having a high resolution and being excellent in convergence in an ultrasound beam, and the like are also possible according to purposes.

Further, by changing two or more factors selected from among a plane view shape of the cavities, the size of the cavities (plane view dimension), the number of pillars and the thickness of the membranes, a wide-band element having more resonance frequencies is obtained. Especially, by successively and gradually changing resonance frequencies of cells to be arranged, a very wide band element is obtained.

Note that, in the element **20**J shown in FIG. **18**, the lower electrodes **12**A are formed on the whole surface of the area where the cell group is formed. On the other hand, though the upper electrodes **16**J are also formed substantially on the whole surface of the area where the cell group is formed, holes **16**JH are formed in areas facing the pillars **14**. Areas

of the membrane immediately above the pillars **14** are non-sensitive areas. However, since the upper electrode **16** does not exist in the non-sensitive areas in the element **20**J, the reception sensitivity is higher.

Here, FIG. **19** shows an example of an end portion of the cell group **10**Z of the element **20** described in the above embodiment. As already described, the plurality of cavities **14**H of the cells **10** constituting the cell group **10**Z communicate with one another. However, it is preferable that an outer peripheral side of cavities **14**H in an outermost peripheral area of the cell group **10**Z be surrounded by a sealing wall constituted by envelope surfaces, and the plurality of cavities **14**H of the cell group **10**Z form a sealed space which does not communicate with an outside. Note that, in the elements **20**A to **20**J also, it is preferable that the plurality of cavities **14**H be sealed spaces which do not communicate with an outside.

In the element in which the plurality of cavities **14**H of the cell group **10**Z are sealed spaces which do not communicate with the outside, an inner pressure in the cavities **14**H do not change even if a surrounding environment changes. Therefore, there is not a possibility that the transmission/reception sensitivity changes.

Twelfth Embodiment

The elements **20** to **20**J described above can be preferably used for an ultrasound endoscope (hereinafter referred to as an "endoscope") **2**.

As shown in FIG. **20**, a radial-type and array-type ultrasound transducer **30** has a plurality of elements **20**, a cylindrical holding member **31** with the elements **20** arranged on an outer surface thereof, and a cable **80**. The lower electrode terminals **12**T and the upper electrode terminals **16**T of the elements **20** are connected to conductor wires **81**A and **81**B of the cable **80**, respectively. Note that the ultrasound array may be of a convex type, a linear type or the like.

FIG. **21** shows an ultrasound endoscope system **1** having the ultrasound endoscope **2** of the twelfth embodiment with the array-type ultrasound transducer **30** (elements **20**) arranged at a distal end portion **47** thereof. The ultrasound endoscope **2** constitutes the ultrasound endoscope system **1** together with an ultrasound observation apparatus **3** and a monitor **4**. The ultrasound endoscope **2** is provided with an elongated insertion portion **41** to be inserted into a body, an operation portion **42** arranged at a proximal end of the insertion portion **41**, and a universal cord **43** extending from a side part of the operation portion **42**.

A connector **44**A connected to a light source apparatus (not shown) is arranged at a proximal end portion of the universal cord **43**. A cable **45** to be detachably connected to a camera control unit (not shown) via a connector **45**A and a cable **46** to be detachably connected to the ultrasound observation apparatus **3** via a connector **46**A extend from the connector **44**A. The monitor **4** is connected to the ultrasound observation apparatus **3**.

The insertion portion **41** is configured by connecting the distal end portion **47**, a bending portion **48** positioned at a rear end of the distal end portion **47**, and a long flexible tube portion **49** having a short diameter and flexibility, which is positioned at a rear end of the bending portion **48** and extends to the operation portion **42**, in that order from a distal end side. The array-type ultrasound transducer **30** is arranged on a distal end side of distal end portion **47**. The endoscope **2** acquires an ultrasound image by the array-type ultrasound transducer **30** arranged at the distal end portion **47**.

The endoscope **2** is provided with the ultrasound transducer elements with a high ultrasound transmission sensitivity and a high ultrasound reception sensitivity and, therefore, is able to acquire a high-resolution image.

Note that it goes without saying that the elements **20** to **20**J can be arranged not only in the endoscope **2** shown in FIG. **21** but also in various small-sized ultrasound diagnostic apparatuses requiring diameter reduction, for example, an IVUS (intra vascular ultrasound) apparatus, an external ultrasound probe or a capsule-type ultrasound endoscope.

The present invention is not limited to the embodiments and the like described above. Various modifications and improvements, for example, a combination of components of the embodiments are possible within a range not departing from the spirit of the present invention.

What is claimed is:

1. An ultrasound transducer element comprising:

a cell group comprising a plurality of ultrasound transducer cells, each of the plurality of ultrasound transducer cells comprising:

a lower electrode arranged on a substrate,

a membrane including an upper electrode arranged facing the lower electrode with a cavity portion positioned between the lower electrode and the upper electrode, and

a plurality of pillars forming the cavity portion to support the membrane,

wherein each cavity portion mutually communicates with other cavity portions;

the plurality of pillars comprises groups of six pillars where each group supports a corresponding portion of the membrane;

the plurality of pillars are cylindrical in cross-section and a diameter of the plurality of pillars is between 1/20 and 1/5 of a distance between adjacent pillars;

the lower electrode comprises a plurality of lower electrode portions each corresponding to one of the groups of six pillars, the plurality of lower electrode portions being connected to each other by a lower electrode wiring; and

the upper electrode comprises a plurality of upper electrode portions each corresponding to one of the groups of six pillars, the plurality of upper electrode portions being connected to each other by an upper electrode wiring.

2. The ultrasound transducer element according to claim **1**, wherein each pillar supports membranes corresponding to a plurality of adjoining ultrasound transducer cells.

3. The ultrasound transducer element according to claim **2**, wherein at least either the lower electrode or the upper electrode of the ultrasound transducer cell is an electrode common to the plurality of ultrasound transducer cells, the common electrode being arranged on a whole surface of a cell group forming area of the substrate.

4. The ultrasound transducer element according to claim **2**, wherein the cell group comprises a plurality kinds of the ultrasound transducer cells that are different in at least any that is selected from among a shape of the cavity, a size of the cavity, the number of pillars and a thickness of the membrane.

5. The ultrasound transducer element according to claim **2**, wherein

shapes of the respective cavities include two kinds of diamond shapes constituting a Penrose tile pattern; and

the pillars are arranged at apexes of the two kinds of diamond shapes.

6. The ultrasound transducer element according to claim **2**, wherein an outer peripheral side of the cavity portions in an outermost peripheral area of the cell group is surrounded by a sealing wall comprising envelope surfaces, and the cavity portions of the cell group are sealed spaces that do not communicate with an outside.

7. An ultrasound endoscope comprising:

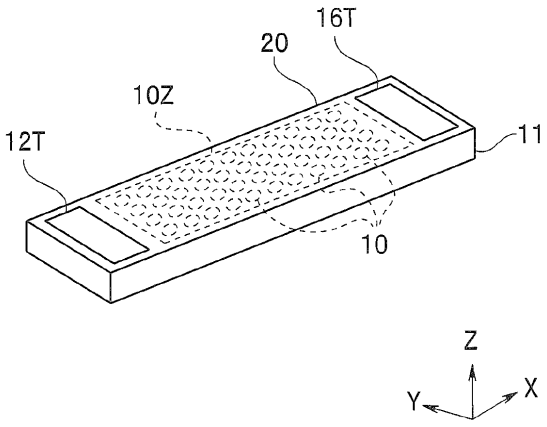
an insertion portion comprising the ultrasound transducer element according to claim **1** arranged at a distal end portion of the insertion portion,

an operation portion arranged on a proximal end side of the insertion portion, and

a universal cord extending from the operation portion.

* * * * *

专利名称(译)	超声换能器元件和超声内窥镜		
公开(公告)号	US10342511	公开(公告)日	2019-07-09
申请号	US14/711176	申请日	2015-05-13
[标]申请(专利权)人(译)	奥林巴斯株式会社		
申请(专利权)人(译)	OLYMPUS CORPORATION		
当前申请(专利权)人(译)	OLYMPUS CORPORATION		
[标]发明人	MATSUMOTO KAZUYA WAKABAYASHI KATSUHIRO		
发明人	MATSUMOTO, KAZUYA WAKABAYASHI, KATSUHIRO		
IPC分类号	A61B8/00 A61B8/12 B06B1/02 H01L49/02		
CPC分类号	A61B8/4483 B06B1/0292 A61B8/12 H01L28/60		
代理机构(译)	斯卡利SCOTT，墨菲和压脚，P.C.		
优先权	2012251444 2012-11-15 JP		
其他公开文献	US20150245811A1		
外部链接	Espacenet		

摘要(译)

一种超声换能器元件，包括由多个超声换能器单元构成的单元组，其中，所述多个超声换能器单元中的每一个包括布置在基板上的下电极，包括面向下电极布置的上电极的膜，所述上电极定位有腔在它们之间，以及通过支撑膜形成空腔的多个柱，并且每个空腔彼此相互连通。