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(54) **ULTRASONIC OSCILLATOR ELEMENT AND ULTRASONIC ENDOSCOPE**

ULTRASCHALLOSZILLATORELEMENT UND ULTRASCHALLENDSKOP

ÉLÉMENT OSCILLANT ULTRASONORE ET ENDOSCOPE ULTRASONORE

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- **KARAKI, Kazuhisa**
Tokyo 192-8507 (JP)
- **HASEGAWA, Mamoru**
Tokyo 192-8507 (JP)
- **WAKABAYASHI, Katsuhiko**
Tokyo 192-8507 (JP)

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(74) Representative: **Schicker, Silvia**

**Wuesthoff & Wuesthoff
Patentanwälte PartG mbB
Schweigerstraße 2
81541 München (DE)**

(73) Proprietor: **Olympus Corporation**

Tokyo 192-8507 (JP)

(72) Inventors:

- **MATSUMOTO, Kazuya**
Tokyo 192-8507 (JP)

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Description

Technical Field

[0001] The present invention relates to an electrostatic capacitive type ultrasound transducer element and an ultrasound endoscope including the ultrasound transducer element.

Background Art

[0002] An ultrasound diagnostic method that irradiates an inside of a body with ultrasound, and images a state of the inside of the body from an echo signal to perform diagnosis is widespread. One of the ultrasound diagnostic apparatuses for use in the ultrasound diagnostic method is an ultrasound endoscope (hereinafter, called "a US endoscope"). In a US endoscope, an ultrasound transducer is placed at a distal end rigid portion of an insertion portion that is introduced into an inside of a body. An ultrasound transducer has a function of converting an electric signal into ultrasound and transmitting the ultrasound to the inside of a body, and receiving ultrasound reflected in the inside of the body and converting the ultrasound into an electric signal.

[0003] For an ultrasound transducer, a ceramic piezoelectric material containing lead that has large environmental load, for example, PZT (lead zirconate titanate) is mainly used. In contrast with this, development of an electrostatic capacitance type ultrasonic transducer (capacitive micro-machined ultrasonic transducer; hereinafter, called "a c-MUT") that does not contain lead in the material and is produced with use of MEMS (micro electro mechanical systems) technique is being advanced.

[0004] As is disclosed in Japanese Patent Application Laid-Open Publication No. 2005-510264, a c-MUT has an ultrasound cell (hereinafter, called "a US cell") in which an upper electrode portion and a lower electrode portion are disposed to face each other via a cavity portion (cavity) as a unit element. In the US cell, a membrane including the upper electrode portion on an upper side of the cavity configures a vibration portion. A plurality of US cells with the respective electrode portions connected by a wiring portion are arranged to configure an ultrasound transducer element (hereinafter, called "a US element").

[0005] The US cell vibrates the membrane including the upper electrode portion by an electrostatic force by application of a voltage to between the lower electrode portion and the upper electrode portion to generate ultrasound. Further, when ultrasound is incident on the membrane from an outside, the membrane deforms to change a spacing of both the electrode portions, and therefore, the ultrasound is converted into an electric signal from a change in electrostatic capacitance.

[0006] Here, since the membrane of a c-MUT is a circular film with an entire outer periphery fixed (restrained) similarly to a drumhead film, a center portion easily displaces, but an outer circumferential portion hardly dis-

places. Therefore, the outer circumferential portion of the membrane has lower transmission and reception efficiency as compared with the center portion. Namely, the conventional electrostatic capacitance type ultrasound transducer element and the ultrasound endoscope having the conventional electrostatic capacitance type ultrasound transducer element sometimes have not been able to be said to have favorable transmission and reception efficiency.

[0007] WO 2009/077961 A2 describes a cMUT device with a substrate in which a pocket is formed. The cMUT device further comprises a flexible membrane coupled to the substrate across the pocket. The flexible membrane is mounted to the substrate along peripheral regions around or about a corresponding periphery of the pocket. A further structure is disposed within the periphery of the pocket which defines and/or at least structurally supports an upward-facing contoured surface. The upward-facing contoured surface extends or protrudes upward and/or outward of the pocket for contacting and/or otherwise cooperatively engaging a downward-facing surface of the flexible membrane in a vicinity of a middle region of the flexible membrane. The structure includes a post disposed substantially in a center of the pocket and extending upward therein in a direction of the flexible membrane, and a lower membrane disposed within and extending across the pocket, including over and across the post.

[0008] JP 2009 055474 A discloses an electrostatic capacitance type ultrasonic transducer comprising a first electrode, a vibrating film disposed on the first electrode while being separated by a cavity hole portion and a second electrode supported on the vibrating film. The hole portion is configured by providing a plurality of void parts having different cross-sectional areas when viewed from a side of the second electrode successively in a direction from the first electrode to the second electrode.

[0009] The present invention has an object to provide an ultrasound transducer element with favorable transmission and reception efficiency and an ultrasound endoscope with favorable transmission and reception efficiency.

Disclosure of Invention

Means for Solving the Problem

[0010] The above objects are addressed by an ultrasound transducer element according to claim 1 and an ultrasound endoscope according to claim 9.

[0011] An ultrasound transducer element may include a plurality of electrostatic capacitance type ultrasound cells each having a lower electrode portion and a membrane including an upper electrode portion that are oriented and disposed via a cavity circular in plan view, wherein a thickness of the cavity strictly monotonically decreases in a curved manner toward an outer circumferential portion from a center portion of the cavity.

[0012] Further, an ultrasound endoscope may include an ultrasound transducer element having a plurality of electrostatic capacitance type ultrasound cells each having a lower electrode portion and a membrane including an upper electrode portion that are oriented and disposed via a cavity circular in plan view, wherein a thickness of the cavity strictly monotonically decreases in a curved manner toward an outer circumferential portion from a center portion of the cavity.

Brief Description of the Drawings

[0013]

Fig. 1 is an outside view for explaining an endoscope system including an ultrasound endoscope of a first embodiment;

Fig. 2 is a perspective view for explaining a distal end portion of the ultrasound endoscope of the first embodiment;

Fig. 3 is a perspective view for explaining a configuration of an ultrasound unit of the ultrasound endoscope of the first embodiment;

Fig. 4 is a top view for explaining a configuration of an ultrasound transducer element of the first embodiment;

Fig. 5 is a partial sectional view taken along a V-V line in Fig. 4;

Fig. 6 is an exploded view of an ultrasound cell of the ultrasound transducer element of the first embodiment;

Fig. 7A is a partial sectional view for explaining a method for producing the ultrasound transducer element of the first embodiment;

Fig. 7B is a partial sectional view for explaining the method for producing the ultrasound transducer element of the first embodiment;

Fig. 7C is a partial sectional view for explaining the method for producing the ultrasound transducer element of the first embodiment;

Fig. 7D is a partial sectional view for explaining the method for producing the ultrasound transducer element of the first embodiment;

Fig. 7E is a partial sectional view for explaining the method for producing the ultrasound transducer element of the first embodiment;

Fig. 8A is a schematic sectional view for explaining drive of the ultrasound transducer element of the first embodiment;

Fig. 8B is a schematic sectional view for explaining drive of the ultrasound transducer element of the first embodiment;

Fig. 9A is a partial sectional view of an ultrasound transducer element of modification 1 of the first embodiment;

Fig. 9B is a partial sectional view of an ultrasound transducer element of modification 2 of the first embodiment;

Fig. 10A is a partial sectional view of an ultrasound transducer element of a second embodiment;

Fig. 10B is a partial sectional view of an ultrasound transducer element of modification 1 of the second embodiment;

Fig. 10C is a partial sectional view of an ultrasound transducer element of modification 2 of the second embodiment; and

Fig. 10D is a partial sectional view of an ultrasound transducer element of modification 3 of the second embodiment.

Best Mode for Carrying Out the Invention

<First Embodiment>

[0014] Hereinafter, an ultrasound transducer element (a US element) 20 of a first embodiment, and an ultrasound endoscope (hereinafter, called "a US endoscope") 2 having the US element 20 will be described with reference to the drawings.

<Configuration of Ultrasound Endoscope>

[0015] As shown in Fig. 1, the US endoscope 2 configures an ultrasound endoscope system 1 with an ultrasound observation apparatus 3 and a monitor 4. The US endoscope 2 includes an elongated insertion portion 21 that is inserted into a body, an operation portion 22 that is arranged at a proximal end of the insertion portion 21, and a universal cord 23 that is extended from a side portion of the operation portion 22.

[0016] At a proximal end portion of the universal cord 23, a connector 24A that is connected to a light source apparatus (not illustrated) is placed. From the connector 24A, a cable 25 that is detachably connected to a camera control unit (not illustrated) via a connector 25A, and a cable 26 that is detachably connected to the ultrasound observation apparatus 3 via a connector 26A are extended. The monitor 4 is connected to the ultrasound observation apparatus 3.

[0017] The insertion portion 21 is configured by a distal end rigid portion (hereinafter, called "a distal end portion") 37, a bending portion 38 that is located at a rear end of the distal end portion 37, and a flexible tube portion 39 that is located at a rear end of the bending portion 38 to reach the operation portion 22, and has a small diameter, a long length and flexibility being connectively provided in sequence from a distal end side. At a distal end side of the distal end portion 37, an ultrasound unit (a US unit) 30 that is an ultrasound transmitting and receiving portion is placed.

[0018] At the operation portion 22, an angle knob 22A that performs bending control of the bending portion 38 in a desired direction, an air/water feeding button 22B that performs air feeding and water feeding operations, a suction button 22C that performs a suction operation, a treatment instrument insertion port 22D to be an inlet

port for a treatment instrument that is introduced to an inside of a body and the like are placed.

[0019] As shown in Fig. 2, at the distal end portion 37 at which the US unit 30 that transmits and receives ultrasound is provided, an illumination lens cover 31 that configures an illumination optical system, an observation lens cover 32 of an observation optical system, a forceps port 33 also used as a suction port, and an air/water feeding nozzle not illustrated are placed.

[0020] As shown in Fig. 3, an ultrasound array (a US array) 40 of the US unit 30 is a radial type transducer group in which long sides of a plurality of US elements 20 rectangular in plan view are connected and disposed to bend in a cylindrical shape. Namely, in the US array 40, 64 of the US elements 20 each with a short side of 0.1 mm or less are placed on a side surface of a cylinder with a diameter of 2 mm, for example.

[0021] Note that the US array 40 is a radial type transducer group, but the US array may be a convex type transducer group that is bent into a convex shape.

<Configuration of Ultrasound Transducer Element>

[0022] As shown in Fig. 4, the ultrasound transducer element 20 that is rectangular in plan view has a transmission and reception portion 60 in which a plurality of ultrasound cells 10 are two-dimensionally disposed in a matrix shape. In each of the US elements 20, an upper electrode terminal 51 and a lower electrode terminal 52 for driving the plurality of ultrasound cells 10 are placed. The plurality of US elements 20 have respective long sides connected to one another.

[0023] Note that the drawings are all schematic views for explanation, and the numbers, the shapes, the thicknesses, and the dimensions of the patterns and the ratios of the sizes and the like differ from reality.

<Basic Structure of Ultrasound Cell>

[0024] As shown in Fig. 5 and Fig. 6, in each of the respective US cells 10, a lower electrode portion 12A and an upper electrode portion 16A are disposed to face each other via a lower insulating layer 13, a gap adjusting portion 19, a cavity 14 and an upper insulating layer 15. Note that hereinafter, a substrate side in a Z direction will be called a lower side, and a protection layer 17 side will be called an upper side.

[0025] Namely, the US cell 10 has the lower electrode layer 12, the lower insulating layer 13, a gap adjusting layer 19A having the cavity 14, the upper insulating layer 15, the upper electrode layer 16 and the protection layer 17 that are stacked in sequence on a substrate 11 formed from silicon that is a base. A part 15B of the upper insulating layer 15 to the protection layer 17 that are directly over the cavity 14 configure a membrane 18. Note that the membrane 18 is illustrated to be thick for explanation in Fig. 6 and the like, but is a vibration film of a small thickness of 1 μm to 10 μm, for example, which is

stretched over an opening of the cavity 14 which is circular in plan view.

[0026] The lower electrode layer 12 is formed by the lower electrode portion 12A and a lower wiring portion 12B. Further, the upper electrode layer 16 is formed by the upper electrode portion 16A and an upper wiring portion 16B. The lower electrode portions 12A of all of the plurality of US cells 10 of the US element 20 are connected to the lower electrode terminal 52 via the lower wiring portions 12B. Similarly, the upper electrode portions 16A of all of the plurality of US cells 10 of the US element 20 are connected to the upper electrode terminal 51 via the upper wiring portions 16B.

[0027] Note that the lower electrode portion 12A, the upper electrode portion 16A, the gap adjusting portion 19 and the cavity 14 are in rotationally symmetrical shape with respect to a center axis O, and are circular in plan view.

[0028] The gap adjusting portion 19 that adjusts a gap that is a thickness (height) of the cavity 14, and is formed from a material with a high dielectric constant is placed on the lower insulating layer 13 in an inside of a cavity forming portion 14A that is a cylindrical cavity portion. In other words, a space of the cavity forming portion 14A that does not have the gap adjusting portion 19 is the cavity 14. A thickness "T" of the gap adjusting portion 19 is, for example, 0 (μm) that is the smallest in a center portion, and strictly monotonically increases in a curved manner toward an outer circumferential portion from the center portion.

[0029] Namely, distribution T(r) of the thickness "T" of the gap adjusting portion 19 with a radius of "R" can be expressed by a function that is shown in (equation 1), for example, and strictly monotonically increases in a curved manner toward the outer circumferential portion from the center portion. Here, a distance from the center axis O is "r", and a thickness of an outer periphery (r = R) of the gap adjusting portion 19 is "TR". As a matter of course, the distribution T(r) does not have to correspond to the function shown in (equation 1) completely, and may have a little difference, for example, a difference of approximately ±5%.

(Equation 1)

$$T(r) = TR \times [1 - J_0(2.4/R \times r)]$$

[0030] J₀ represents a Bessel function of the order 0, J₀(0) = 1 and J₀(2.4) = 0.

[0031] Here, (equation 1) is an expression using a Bessel function of the zeroth order that shows an envelope of vibration of a circular plane vibration plate the outer periphery of which is restrained.

[0032] The gap adjusting portion 19 is preferably formed from a material with a high dielectric constant, for example, SiO₂ (K_s = 3.8) with a relative dielectric constant K_s being 3 or more, and especially preferably formed from SiN, for example, with a relative dielectric

constant K_s being 5 or more. As a matter of course, Al_2O_3 ($K_s = 8.5$), Ta_2O_5 ($K_s = 20$ to 25), TiO_2 ($K_s = 40$ to 110), $HfOF$, or HfO_2 , and further barium titanate ceramics or the like, which has a higher dielectric constant K_s , may be used, and from the viewpoint of easiness of a forming method and the like, the upper limit of the relative dielectric constant K_s is approximately 150.

[0033] A thickness (height) " t " of the cavity 14 strictly monotonically decreases in a curved manner toward the outer circumferential portion from a center O of the cavity 14 in response to thickness distribution of the gap adjusting portion 19, and is expressed by a Bessel function $t(r)$ of the zeroth order shown in (equation 2). Namely, the cavity 14 is in a so-called downward convex shape. Note that " t_0 " represents a thickness (height) " t " at the center ($r = 0$) of the cavity 14, and equals to the thickness " TR " of the outer periphery ($r = R$) of the gap adjusting portion 19.

(Equation 2)

$$t(r) = t_0 \times J_0(2.4/R \times r)$$

[0034] Namely, the thickness distribution (variation state) $t(r)$ of the thickness " t " of the cavity 14 is the same as a theoretical deformation state of the membrane 18 when driven.

[0035] Next, with use of Fig. 7A to Fig. 7E, a method for producing the US element 20 will be described.

< Formation of Lower Electrode Layer >

[0036] A conductive layer formed from conductive silicon or a metal, for example, copper, gold, Mo, Ta or aluminum is deposited on an entire surface of the substrate 11 on which an insulating layer (not illustrated) is formed by a sputtering method, a CVD (chemical vapor deposition) method or the like. Subsequently, after a mask pattern formed from resist is formed on the conductive layer by photolithography, the conductive layer which is not covered with the mask pattern is selectively removed by etching, and thereby, the lower electrode layer 12 is formed.

< Formation of Lower Insulating Layer >

[0037] The lower insulating layer 13 formed from an insulating material such as SiN is deposited in such a manner as to cover the lower electrode layer 12 by a CVD method, for example. In accordance with necessity, a surface of the lower insulating layer 13 is flattened by a CMP (chemical mechanical polish) method after deposition. Subsequently, an intermediate insulating layer 15A formed from SiN, for example, is further formed on the lower insulating layer 13. A thickness " t_0 (TR)" of the intermediate insulating layer 15A corresponds to a thickness (height) of the cavity forming portion 14A.

[0038] As shown in Fig. 7A, with use of a mask pro-

duced by a photolithography method, the intermediate insulating layer 15A is selectively removed by etching and the cavity forming portion 14A is formed. When the lower insulating layer 13 and the intermediate insulating layer 15A are formed from different materials, etching is performed with a chemical solution, gas or the like that selectively etches the intermediate insulating layer 15A. When the lower insulating layer 13 and the intermediate insulating layer 15A are formed from the same material, for example, SiN, the surface of the intermediate insulating layer 15A is flattened by a CMP method in accordance with necessity, after which, only the cavity forming portion 14A may be etched until the cavity forming portion 14A has a maximum height (depth) " t_0 " of the cavity 14, based on an etching rate of the intermediate insulating layer 15A.

< Formation of Gap Adjusting Portion >

[0039] The gap adjusting layer 19A formed from a material with a high dielectric constant is deposited on the surface of the intermediate insulating layer 15A to have a maximum thickness (height) " TR (t_0)" of the cavity forming portion 14A, or more. Subsequently, a portion corresponding to a film thickness (convex portion) of the gap adjusting layer 19A is polished by a CMP method and a surface is flattened. Thereupon, a structure in which the gap adjusting layer 19A is buried only in the inside of the cavity forming portion 14A is produced.

[0040] As shown in Fig. 7B, a photoresist is exposed via a gray scale photo-mask or the like, and thereby a resist mask 63 in which a thickness strictly monotonically increases toward the outer circumferential portion from the center portion is produced. Namely, the thickness of the resist mask 63 strictly monotonically increases in a curved manner toward the outer circumferential portion from the center portion as shown by (equation 1).

[0041] Etch back processing is performed under dry etching conditions in which etching rates of the resist mask 63 and the gap adjusting layer 19A are equal to each other, whereby the gap adjusting portion 19 formed from a material with a high dielectric constant with a surface profile shown in (equation 1) is produced in the inside of the cavity forming portion 14A, as shown in Fig. 7C.

< Formation of Sacrifice Layer >

[0042] A sacrifice layer material composed of tungsten, for example, is deposited to a thickness of the maximum thickness (TR) of the cavity forming portion 14A or more. Subsequently, when polishing by a CMP method is performed, a structure including a sacrifice layer 61 in a cavity shape is obtained as shown in Fig. 7D. A maximum thickness " t_0 (TR)" of the sacrifice layer 61 after polishing is, for example, $0.05 \mu m$ to $0.3 \mu m$, and preferably is $0.05 \mu m$ to $0.15 \mu m$.

<Formation of Upper Insulating Layer>

[0043] The upper insulating layer 15 is formed by a similar method and from a similar material to the lower insulating layer 13, for example. Subsequently, at a pre-determined position of the upper insulating layer 15, an opening portion (not illustrated) into which an etchant is poured is formed in order to remove the sacrifice layer 61.

<Formation of Cavity>

[0044] The sacrifice layer 61 is selectively removed by etching, and thereby the cavity 14 is formed. When tungsten (W) is used as the sacrifice layer 61, and SiN is used as the lower insulating layer 13 and the upper insulating layer 15, for example, a hydrogen peroxide solution (H_2O_2) is used as the etchant. Further, when conductive polycrystalline silicon is used as the sacrifice layer 61, and SiN is used as the lower insulating layer 13 and the upper insulating layer 15, xenon fluoride gas (XeF_2) is used as the etchant.

<Formation of Upper Electrode Layer>

[0045] By a method similar to the method for forming the lower electrode layer 12, the upper electrode layer 16 is formed.

<Formation of Protection Layer>

[0046] As shown in Fig. 7E, the upper insulating layer 15 is covered with the protection layer 17. The protection layer 17 has not only a protection function, but also a function of connecting the plurality of US elements 20. The protection layer 17 is formed from a flexible resin such as polyimide, epoxy, acryl, or poly-para-xylene, and among them, polyimide is preferable since polyimide has high chemical resistance and flexibility, and is easy to process. Note that the protection layer 17 may be of a double layer structure in which a second insulating layer having biocompatibility is further formed on a first insulating layer.

[0047] Note that the plan view of the cavity 14 does not have to be perfect circular, but may be substantially circular. Further, the plan view of the cavity 14 may be in a polygonal shape that is substantially circular. Namely, a shape of the cavity forming portion 14A is not limited to a circular cylinder shape, and may be a polygonal column shape or the like. When the cavity forming portion 14A is in a polygonal column shape, shapes in plan view of the upper electrode portion 16A and the lower electrode portion 12A are preferably also made polygonal. In the gap adjusting portion 19, a range of an inscribed circle can satisfy the thickness distribution.

[0048] The plurality of US elements 20 are disposed by being bent into a radial shape in a connecting direction shown in Fig. 4, and thereby the US array 40 shown in Fig. 2 and Fig. 3 is produced. The US array 40 is joined

to an outer circumferential face of a cylinder with a pre-determined outside diameter, for example. Further, a coaxial cable bundle 35 is connected to the US array 40, and the US unit 30 is produced.

<Action of US Element/US Cell>

[0049] Next, an action of the US element 20 will be described with use of Fig. 8A and Fig. 8B. Note that in Fig. 8A and Fig. 8B, the lower insulating layer 13, the upper insulating layer 15, the protection layer 17 and the like are not shown, and explanation of an influence thereof will be omitted.

[0050] As shown in Fig. 8A, the lower electrode portion 12A is connected to a voltage signal generating section 3A of the ultrasound observation apparatus 3 via the lower electrode terminal 52. The upper electrode portion 16A is connected to a capacitive signal detecting section 3B via the upper electrode terminal 51 to be at a ground potential. The capacitive signal detecting section 3B detects a capacitive signal (a current change) at a time of receiving ultrasound.

[0051] At a time of ultrasound generation (drive time), the voltage signal generating section 3A applies a drive voltage signal including a bias voltage to the lower electrode portion 12A. When a voltage is applied to the lower electrode portion 12A, the upper electrode portion 16A at a ground potential is attracted to the lower electrode portion 12A by an electrostatic force as shown in Fig. 8B, and therefore the membrane 18 including the upper electrode portion 16A deforms into a concave shape. Note that the outer circumferential portion of the cavity 14 has a small height (thickness) "t", but does not interfere with deformation of the membrane 18, since a deformation amount of the outer circumferential portion of the membrane 18 is small.

[0052] When voltage application to the lower electrode portion 12A becomes nonexistent, the membrane 18 is restored to be in an original shape shown in Fig. 8A by an elastic force. Ultrasound is generated by vibration by (deformation/restoration) of the membrane 18.

[0053] Here, in the cavity 14 of the conventional US element, a whole of an inside thereof is made of air (vacuum) with a relative dielectric constant of "1", and the thickness thereof is the same and "t₀" from the center portion to the outer circumferential portion. In other words, the cavity 14 of the conventional US element is the same as the cavity forming portion 14A of the US element 20.

[0054] In contrast with this, the gap adjusting portion 19 is placed in the inside of the cavity forming portion 14A of the US element 20. A relative dielectric constant Ks of the gap adjusting portion 19 formed from a material with a high dielectric coefficient is larger than "1". Therefore, a dielectric equivalent spacing "Teff" of the gap adjusting portion 19 is expressed by (equation 3) in a position at which the distance from a center of the cavity 14 is "r". Here, the dielectric equivalent spacing "Teff" is an

electrostatic spacing with the relative dielectric constant K_s taken into consideration with respect to a physical spacing "T".

(Equation 3)

$$T_{eff}(r) = T(r)/K_s$$

[0055] Here, when the relative dielectric constant K_s is sufficiently larger than "1", for example, in the case of $K_s \geq 3$, the dielectric equivalent spacing "Teff" can be regarded as substantially "zero". Namely, in the US element 20, the gap adjusting portion 19 can be regarded as electrostatically absent.

[0056] Therefore, the dielectric equivalent spacing "teff" of the cavity 14 can be expressed by being approximated by (equation 4).

(Equation 4)

$$teff = t_0 - T(r)$$

[0057] In other words, a physical spacing between the lower electrode portion 12A and the upper electrode portion 16A that are disposed to face each other via the cavity 14 is uniform. However, the dielectric equivalent spacing "Teff" that is an effective thickness of the cavity 14, namely, the electrostatic spacing (effective distance between the electrodes) is the maximum at a center ($r = 0$), and decreases in a curved manner toward the outer circumferential portion. Since an electrostatic force is proportional to the effective distance between the electrodes, the electrostatic force that acts between the electrodes increases in the US element 20 more than in the conventional US element in which the distance between the electrodes is uniform. Therefore, the US element 20 has favorable generation efficiency of ultrasound.

[0058] Further, in the US element 20, an entire undersurface of the membrane 18 that is attracted to the lower electrode portion 12A deforms in such a manner as to contact and stretch onto the top surface of the gap adjusting portion 19, when driven. Therefore, the deformation state of the membrane 18 when driven becomes the same as the shape of the top surface of the gap adjusting portion 19 shown by (equation 1) and the like.

[0059] As already described, the shape shown by (equation 1) or the like is a theoretical deformation shape of the vibration film.

[0060] The ultrasound generated by the US cell 10 that deforms into a theoretical state becomes an ideal waveform with little distortion. Therefore, the US element 20 having the US cells 10 has favorable transmission efficiency of ultrasound.

[0061] Note that when the entire undersurface of the membrane 18 deforms significantly in such a manner as to stretch, namely, abut onto the top surface of the gap adjusting portion 19, a gas may be held in the inside in a compressed state when the gas is present in the cavity

14, or may be released to an outside via an opening portion (not illustrated) that is formed to cause an etchant to flow therein, for example.

[0062] Further, in the US element 20, the gap adjusting portion 19 formed from a material with a high dielectric coefficient with a higher insulating property than air is placed between the electrodes, and therefore, a withstand voltage between electrodes is high.

[0063] The US element 20 having the US cells 10 has favorable reception efficiency of ultrasound. As is already described, in the US cell 10 in which the distance between the electrodes decreases from the center portion to the outer circumferential portion, the electrostatic capacitance increases more than in the conventional US cell in which the distance between the electrodes is uniform. Therefore, in the US cell 10, a change rate of a charge amount increases even if the membrane 18 deforms to the extent that is the same as in the conventional US cell. Furthermore, the outer circumferential portion of the membrane 18 has a small deformation amount since the outer circumferential portion is restrained by the intermediate insulating layer 15A, but since the distance between the electrodes is short, the change in the charge amount is large.

[0064] As in the above explanation, the US element 20 has favorable transmission and reception efficiency of ultrasound. The US endoscope 2 including the US element 20 has favorable transmission and reception efficiency of ultrasound.

<Modification of First Embodiment>

[0065] As shown in Fig. 8A and the like, in the US element 20, the thickness of the cavity is varied because the gap adjusting portion 19 that is formed from a material with a high dielectric constant in the inside of the cavity forming portion 14A that is a cylindrical cavity portion formed in the intermediate insulating layer 15A is placed. In contrast with this, as in a US cell 10A shown in Fig. 9A, a part of the intermediate insulating layer 15A formed from a material with a high dielectric constant may be made a cavity 14A1 in which a thickness varies. Namely, a gap adjusting portion of a US element 20A of modification 1 of the first embodiment shown in Fig. 9A is a part of the intermediate insulating layer 15A.

[0066] Further, as shown in Fig. 9B, a cavity 14B of a US cell 10B of a US element 20B of modification 2 of the first embodiment is a so-called upward concave shape with a thickness thereof strictly monotonically increasing in a curved manner toward an outer circumferential portion from a center portion similarly to that of the US element 20.

[0067] The US element 20A and the US element 20B have the same effect as the US element 20.

<Second Embodiment>

[0068] Hereinafter, with reference to the drawings, a

US element 20C having a US cell 10C of a second embodiment will be described. Since the US cell 10C and the US element 20C are analogous to the US cell 10 and the US element 20 of the first embodiment, the same components will be assigned with the same reference signs, and explanation thereof will be omitted.

[0069] As shown in Fig. 10A, in the US cell 10C, a thickness T12 of a lower electrode portion 12C that is covered with the lower insulating layer 13 increases strictly monotonically in a curved manner toward an outer periphery from a center. Therefore, a physical spacing between the lower electrode portion 12C and the upper electrode portion 16A strictly monotonically decreases in a curved manner toward an outer circumferential portion from a center. Therefore, a thickness "t" of a cavity 14C strictly monotonically increases in a curved manner toward an outer circumferential portion from a center portion.

[0070] Distribution of the thickness T12 of the lower electrode portion 12C of the US element 20C and distribution of the thickness "t" of the cavity 14C can be shown by a Bessel function of the zeroth order of (equation 1) or (equation 2) similarly to the thickness variation of the gap adjusting portion 19 of the US element 20 of the first embodiment. Namely, in the US element 20C, a variation state of the thickness of the cavity 14C is the same as a deformation state of a membrane when driven.

[0071] In other words, a top surface shape of the lower electrode portion 12C that is covered with the lower insulating layer 13 is the same as an undersurface shape of the cavity 14C.

[0072] The lower electrode portion 12C is formed by performing etch back processing with use of a resist mask or the like in which a thickness strictly monotonically increases toward an outer circumferential portion from a center portion similarly to the gap adjusting layer 19A.

< Modification of Second Embodiment >

[0073] As shown in Fig. 10B, in a US cell 10D of a US element 20D of modification 1 of the second embodiment, a convex portion a depth of which is expressed by a Bessel function of the zeroth order, and strictly monotonically decreases toward an outer circumferential portion from a center portion is formed in a substrate 11D, and a lower electrode portion 12D is formed thereon. Therefore, a physical spacing between the lower electrode portion 12D and the upper electrode portion 16D strictly monotonically decreases in a curved manner toward the outer circumferential portion from a center. A thickness "t" of a cavity 14D strictly monotonically increases in a curved manner toward the outer circumferential portion from the center portion.

[0074] Further, in a US cell 10E of a US element 20E of modification 2 of the second embodiment shown in Fig. 10C, an upper electrode portion 16E is deformed into a convex shape that is expressed by a Bessel function of the zeroth order by an internal stress of the mem-

brane 18. Therefore, a physical spacing between the lower electrode portion 12A and an upper electrode portion 16E strictly monotonically decreases in a curved manner toward an outer circumferential portion from a center.

Therefore, a thickness "t" of a cavity 14E strictly monotonically decreases in a curved manner toward the outer circumferential portion from the center portion.

[0075] Furthermore, a US cell 10F of a US element 20F of modification 3 of the second embodiment shown in Fig. 10D has a cavity 14F in a double convex shape by a cavity in a downward convex shape that is expressed by a Bessel function of the zeroth order, and a cavity in an upward convex shape that is expressed by a Bessel function of the zeroth order being combined. A physical spacing between an upper electrode portion 16F and a lower electrode portion 12F on a substrate 11F strictly monotonically decreases in a curved manner toward an outer circumferential portion from a center.

[0076] The US elements 20C to 20F all have the same effect as the US element 20. Further, unlike the US element 20, the US elements 20C to 20F are easily produced since formation of the gap adjusting portion 19 is not necessary.

[0077] As described above, the US elements 20A to 20F have favorable ultrasound transmission and reception efficiency similarly to the US element 20. The US endoscopes 2A to 2F including the US elements 20A to 20F have favorable ultrasound transmission and reception efficiency.

[0078] Note that depending on the restraint conditions of the outer periphery of the membrane 18, the thickness (height) distribution $t(r)$ of the cavities 14 to 14F shown in the first embodiment, the second embodiment and the modifications may be expressed by an arc function shown in (equation 5) or a sine function shown in (equation 6) if the thickness (height) distribution $t(r)$ can be expressed by a function of the thickness "t" strictly monotonically decreasing in a curved manner with increase of $[r]$.

(Equation 5)

$$t(r) = t_0 \times [1 - (r/R)^2]$$

(Equation 6)

$$t(r) = t_0 \times [1 - \sin(\pi/2 \times r/R)]$$

[0079] Further, the shape of the cavity is not limited to the shapes of the cavities 14 to 14F, and the thickness of the cavity may strictly monotonically decrease in a curved manner toward the outer circumferential portion from the center portion. For example, the top surface of the cavity may be bent significantly while the undersurface may be bent significantly while the undersurface may be bent a little. Contrary to this, the top surface of

the cavity may be bent a little, while the undersurface may be bent significantly.

Claims

1. An ultrasound transducer element (20; 20A; 20B; 20C; 20D; 20E; 20F), comprising:

a plurality of electrostatic capacitance type ultrasound cells (10; 10A; 10B; 10C; 10D; 10E; 10F) each having a lower electrode portion (12A; 12C; 12D; 12F) and a membrane (18) including an upper electrode portion (16A; 16D; 16E; 16F) that are oriented and disposed via a cavity (14; 14A1; 14B; 14C; 14D; 14E; 14F) circular in plan view,

characterized in that the thickness of the cavity (14; 14A1; 14B; 14C; 14D; 14E; 14F) strictly monotonically decreases such that the cavity (14; 14A1; 14B; 14C; 14D; 14E; 14F) has a curved shape toward an outer circumferential portion from the center axis (O) of the cavity (14; 14A1; 14B; 14C; 14D; 14E; 14F), wherein the thickness of the cavity (14; 14A1; 14B; 14C; 14D; 14E; 14F) at the center axis (O) is t_0 and the thickness distribution $t(r)$ decreases toward the outer circumferential portion from the center axis (O) according to

$$t(r) = t_0 \times J_0(2.4/R \times r),$$

wherein r is the distance from the center axis (O), R is the distance of the circumference of the cavity from the center axis (O) and J_0 is the Bessel function of the zeroth order, within a difference of approximately $\pm 5\%$.

2. The ultrasound transducer element according to claim 1, wherein a physical spacing or a dielectric equivalent spacing of the lower electrode portion (12A; 12C; 12D; 12F) and the upper electrode portion (16A; 16D; 16E; 16F) strictly monotonically decreases in a curved manner toward the outer circumferential portion from the center axis (O).
3. The ultrasound transducer element according to claim 2, wherein a thickness distribution of the cavity (14; 14A1; 14B; 14C; 14D; 14E; 14F) toward the outer circumferential portion from the center axis (O) is selected such that the cavity (14; 14A1; 14B; 14C; 14D; 14E; 14F) has a shape that corresponds to a theoretical deformation shape of the membrane (18) when driven.

4. The ultrasound transducer element according to claim 1, wherein a gap adjusting portion (19) formed from a dielectric with a thickness thereof strictly monotonically increasing in a curved manner toward an outer circumferential portion from a center portion is included between the lower electrode portion (12A; 12C; 12D; 12E) and the upper electrode portion (16A; 16D; 16E; 16F), wherein the thickness distribution $T(r)$ of the gap adjusting portion increases toward the outer circumferential portion from the center axis (O) according to

$$T(r) = TR \times (1 - J_0(2.4/R \times r)),$$

wherein TR is the thickness of the gap adjusting portion at the outer circumferential portion, within a difference of approximately $\pm 5\%$.

5. The ultrasound transducer element according to claim 4, wherein a relative dielectric constant of the dielectric is three or more.
6. The ultrasound transducer element according to claim 5, wherein an undersurface of the membrane (18) that is attracted to the lower electrode portion (12A; 12C; 12D; 12E) when driven contacts a top surface of the gap adjusting portion (19).
7. The ultrasound transducer element according to claim 1, wherein a top surface shape of the lower electrode portion (12A; 12C; 12D; 12E) covered with a lower insulating layer (13) is the same as an undersurface shape of the cavity (14; 14A1; 14B; 14C; 14D; 14E; 14F).
8. The ultrasound transducer element according to claim 7, wherein an undersurface of the membrane (18) attracted to the lower electrode portion (12A; 12C; 12D; 12E) when driven contacts a top surface of the insulating layer (13).
9. An ultrasound endoscope (2), comprising: the ultrasound transducer element (20; 20A; 20B; 20C; 20D; 20E; 20F) according to any one of claim 1 to claim 8.

Patentansprüche

1. Ultraschallwandlerelement (20; 20A; 20B; 20C; 20D; 20E; 20F), das umfasst:

eine Mehrzahl von Ultraschallzellen (10; 10A; 10B; 10C; 10D; 10E; 10F) vom elektrostatisch kapazitivem Typ, die jeweils einen unteren Elektrodenabschnitt (12A; 12C; 12D; 12F) und eine Membran (18) mit einem oberen Elektrodenabschnitt (16A; 16D; 16E; 16F) umfassen, und die über einen Hohlraum (14; 14A1; 14B; 14C; 14D; 14E; 14F) in Draufsicht kreisförmig ausgerichtet und angeordnet sind;

dadurch gekennzeichnet, dass die Dicke des Hohlraums (14; 14A1; 14B; 14C; 14D; 14E; 14F) streng monoton abnimmt, so dass der Hohlraum (14; 14A1; 14B; 14C; 14D; 14E; 14F) in Richtung eines Außenumfangsabschnitts von der Mittelachse (O) des Hohlraums (14; 14A1; 14B; 14C; 14D; 14E; 14F) eine gekrümmte Gestalt aufweist, wobei die Dicke des Hohlraums (14; 14A1; 14B; 14C; 14D; 14E; 14F) auf der Mittelachse (O) t_0 ist und die Dickenverteilung $t(r)$ in Richtung des Außenumfangsabschnitts von der Mittelachse (O), innerhalb einer Differenz von ungefähr $\pm 5\%$, gemäß $t(r) = t_0 \times J_0(2,4 / R \times r)$ abnimmt,

wobei r die Distanz von der Mittelachse (O) ist, R die Distanz des Umfangs des Hohlraums von der Mittelachse (O) ist und J_0 die Bessel-Funktion der nullten Ordnung ist.

2. Ultraschallwandlerelement nach Anspruch 1, wobei eine physikalischer Abstand oder ein dielektrischer Äquivalenzabstand des unteren Elektrodenabschnitts (12A; 12C; 12D; 12F) und des oberen Elektrodenabschnitts (16A; 16D; 16E; 16F) auf gekrümmte Weise in Richtung des Außenumfangsabschnitts von der Mittelachse (O) streng monoton abnimmt.
3. Ultraschallwandlerelement nach Anspruch 2, wobei eine Dickenverteilung des Hohlraums (14; 14A1; 14B; 14C; 14D; 14E; 14F) in Richtung des Außenumfangsabschnitts von der Mittelachse (O) so ausgewählt ist, dass der Hohlraum (14; 14A1; 14B; 14C; 14D; 14E; 14F) eine Gestalt aufweist, die einer theoretischen Verformungsgestalt der Membran (18) in Betrieb entspricht.
4. Ultraschallwandlerelement nach Anspruch 1, wobei ein Abstandseinstellabschnitt (19), der aus einem Dielektrikum gebildet ist, dessen Dicke in gekrümmter Weise in Richtung eines Außenumfangsabschnitts von einem Mittelabschnitt streng monoton zunimmt, zwischen dem unteren Elektrodenabschnitt (12A; 12C; 12D; 12E) und dem oberen Elektrodenabschnitt (16A; 16D; 16E; 16F) vorgesehen ist, wobei die Dickenverteilung $T(r)$ des Abstandseinstellabschnitts in Richtung des Außenumfangsabschnitts von der Mittelachse (O), innerhalb einer

Differenz von ungefähr $\pm 5\%$, gemäß

$$T(r) = TR \times (1 - J_0(2,4 / R \times r))$$

zunimmt, wobei TR die Dicke des Abstandseinstellabschnitts am Außenumfangsabschnitt ist.

5. Ultraschallwandlerelement nach Anspruch 4, wobei eine relative dielektrische Konstante des Dielektrikums drei oder höher ist.
6. Ultraschallwandlerelement nach Anspruch 5, wobei eine Unterseite der Membran (18), die im angetriebenen Zustand zum unteren Elektrodenabschnitt (12A; 12C; 12D; 12E) gezogen, mit einer Oberseite des Abstandseinstellabschnitts (19) in Kontakt gelangt.
7. Ultraschallwandlerelement nach Anspruch 1, wobei eine Oberseitengestalt des unteren Elektrodenabschnitts (12A; 12C; 12D; 12D), die mit einer unteren Isolierschicht (13) bedeckt ist, gleich wie eine Unterseitengestalt des Hohlraums (14; 14A1; 14B; 14C; 14D; 14E; 14F) ist.
8. Ultraschallwandlerelement nach Anspruch 7, wobei eine Unterseite der Membran (18), die im angetriebenen Zustand zum unteren Elektrodenabschnitt (12A; 12C; 12D; 12E) gezogen wird, mit einer Oberseite der Isolierschicht (13) in Kontakt gelangt.
9. Ultraschallendoskop (2), das umfasst: das Ultraschallwandlerelement (20; 20A; 20B; 20C; 20D; 20E; 20F) nach einem der Ansprüche 1 bis 8.

Revendications

1. Élément de transducteur à ultrasons (20 ; 20A ; 20B ; 20C ; 20D ; 20E ; 20F) comprenant : une pluralité de cellules ultrasonores de type à capacité électrostatique (10 ; 10A ; 10B ; 10C ; 10D ; 10E ; 10F) ayant chacune une partie d'électrode inférieure (12A ; 12C ; 12D ; 12F) et une membrane (18) comprenant une partie d'électrode supérieure (16A ; 16D ; 16E ; 16F) qui sont orientées et disposées par l'intermédiaire d'une cavité (14 ; 14A1 ; 14B ; 14C ; 14D ; 14E ; 14F) circulaire en vue en plan, **caractérisé par le fait que** l'épaisseur de la cavité (14 ; 14A1 ; 14B ; 14C ; 14D ; 14E ; 14F) diminue de manière strictement monotone de telle sorte que la cavité (14 ; 14A1 ; 14B ; 14C ; 14D ; 14E ; 14F) a une forme incurvée vers une partie circonférentielle externe à partir de l'axe central (O) de la cavité (14 ; 14A1 ; 14B ; 14C ; 14D ; 14E ; 14F), l'épaisseur de la cavité (14 ; 14A1 ; 14B ; 14C ; 14D ;

- 14E ; 14F) au niveau de l'axe central (O) étant t_0 et la distribution d'épaisseur $t(r)$ diminuant vers la partie circonférentielle externe à partir de l'axe central (O) conformément à $t(r) = t_0 \times J_0(2,4/R \times r)$, r étant la distance à partir de l'axe central (O), R étant la distance de la circonférence de la cavité à partir de l'axe central (O), et J_0 étant la fonction de Bessel d'ordre zéro, dans les limites d'une différence d'approximativement $\pm 5\%$.
2. Élément de transducteur à ultrasons selon la revendication 1, dans lequel un espacement physique ou un espacement équivalent diélectrique de la partie d'électrode inférieure (12A ; 12C ; 12D ; 12F) et de la partie d'électrode supérieure (16A ; 16D ; 16E ; 16F) diminue de manière strictement monotone et d'une manière incurvée vers la partie circonférentielle externe à partir de l'axe central (O).
 3. Élément de transducteur à ultrasons selon la revendication 2, dans lequel une distribution d'épaisseur de la cavité (14 ; 14A1 ; 14B ; 14C ; 14D ; 14E ; 14F) vers la partie circonférentielle externe à partir de l'axe central (O) est choisie de telle sorte que la cavité (14 ; 14A1 ; 14B ; 14C ; 14D ; 14E ; 14F) a une forme qui correspond à une forme de déformation théorique de la membrane (18) lorsqu'elle est excitée.
 4. Élément de transducteur à ultrasons selon la revendication 1, dans lequel une partie d'ajustement d'intervalle (19) formée à partir d'un diélectrique avec une épaisseur de celui-ci qui augmente de manière strictement monotone et d'une manière incurvée vers une partie circonférentielle externe à partir d'une partie centrale est comprise entre la partie d'électrode inférieure (12A ; 12C ; 12D ; 12E) et la partie d'électrode supérieure (16A ; 16D ; 16E ; 16F), la distribution d'épaisseur $T(r)$ de la partie d'ajustement d'intervalle augmentant vers la partie circonférentielle externe à partir de l'axe central (O) conformément à $T(r) = TR \times (1 - J_0(2,4/R \times r))$, TR étant l'épaisseur de la partie d'ajustement d'intervalle au niveau de la partie circonférentielle externe, dans les limites d'une différence d'approximativement $\pm 5\%$.
 5. Élément de transducteur à ultrasons selon la revendication 4, dans lequel une constante diélectrique relative du diélectrique est de trois ou plus.
 6. Élément de transducteur à ultrasons selon la revendication 5, dans lequel une surface inférieure de la membrane (18) qui est attirée vers la partie d'électrode inférieure (12A ; 12C ; 12D ; 12E) lorsqu'elle est excitée en-
- tre en contact avec une surface supérieure de la partie d'ajustement d'intervalle (19).
7. Élément de transducteur à ultrasons selon la revendication 1, dans lequel une forme de surface supérieure de la partie d'électrode inférieure (12A ; 12C ; 12D ; 12D) recouverte d'une couche isolante inférieure (13) est la même qu'une forme de surface inférieure de la cavité (14 ; 14A1 ; 14B ; 14C ; 14D ; 14E ; 14F).
 8. Élément de transducteur à ultrasons selon la revendication 7, dans lequel une surface inférieure de la membrane (18) attirée vers la partie d'électrode inférieure (12A ; 12C ; 12D ; 12E) lorsqu'elle est excitée entre en contact avec une surface supérieure de la couche isolante (13).
 9. Endoscope ultrasonore (2), comprenant : l'élément de transducteur à ultrasons (20 ; 20A ; 20B ; 20C ; 20D ; 20E ; 20F) selon l'une quelconque des revendications 1 à 8.

FIG.1

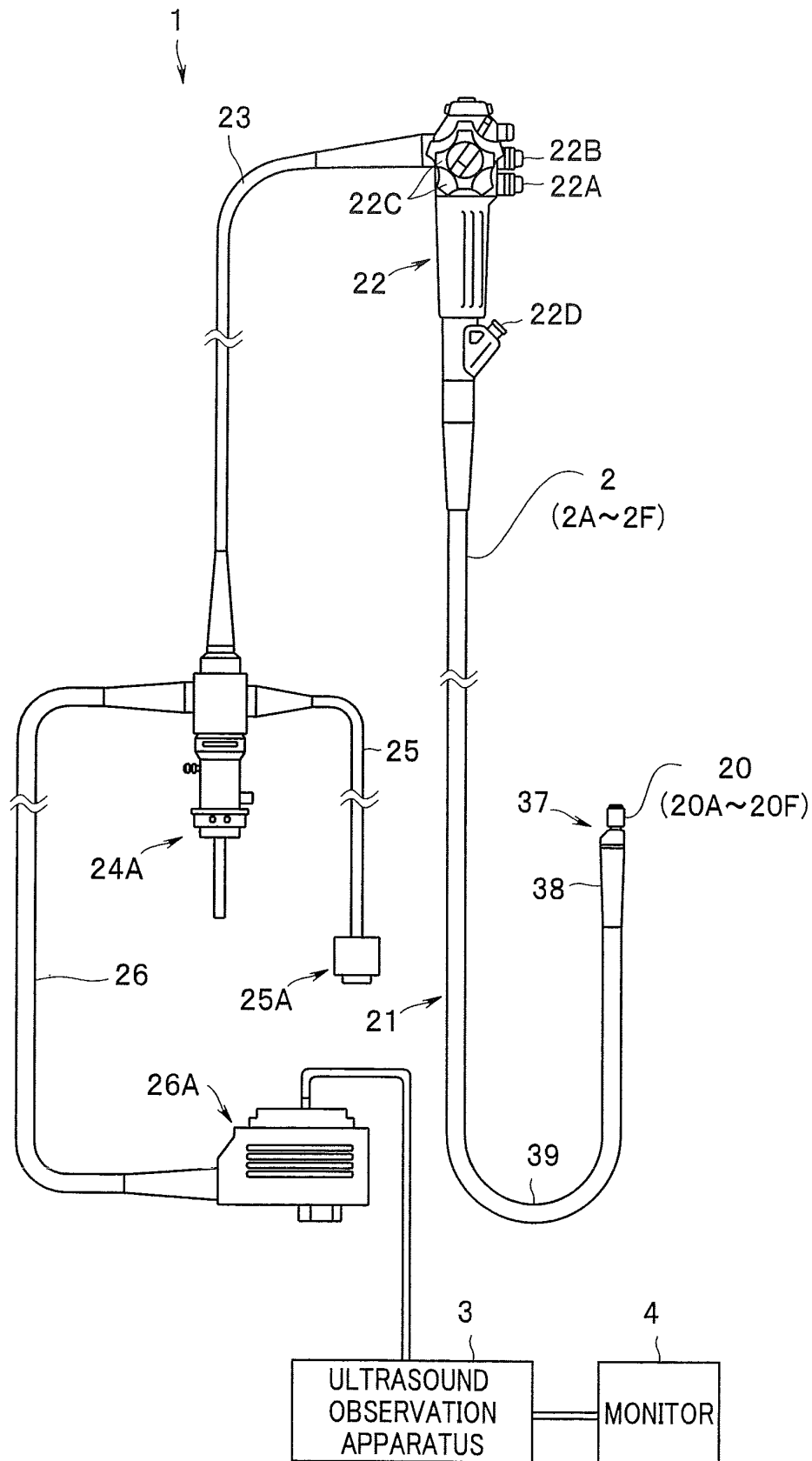


FIG.2

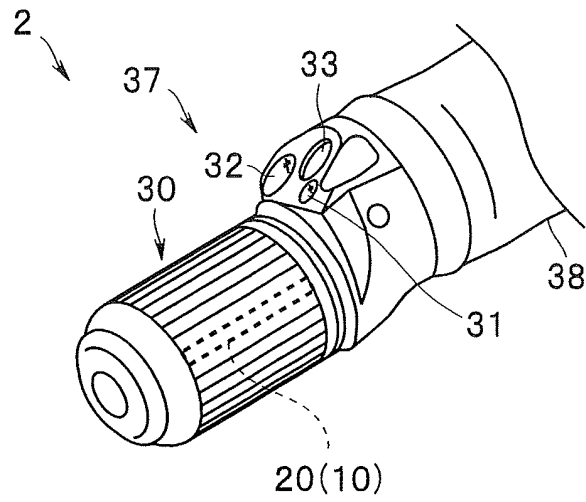


FIG.3

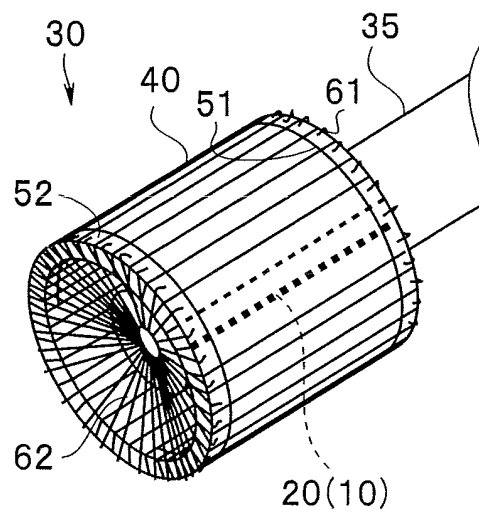


FIG.4

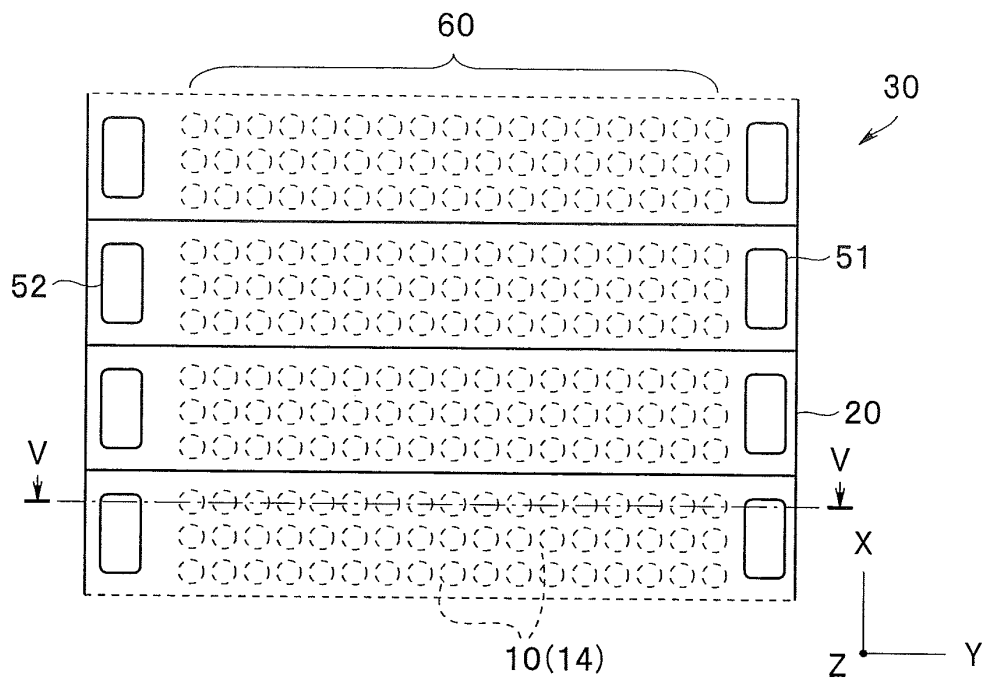


FIG.5

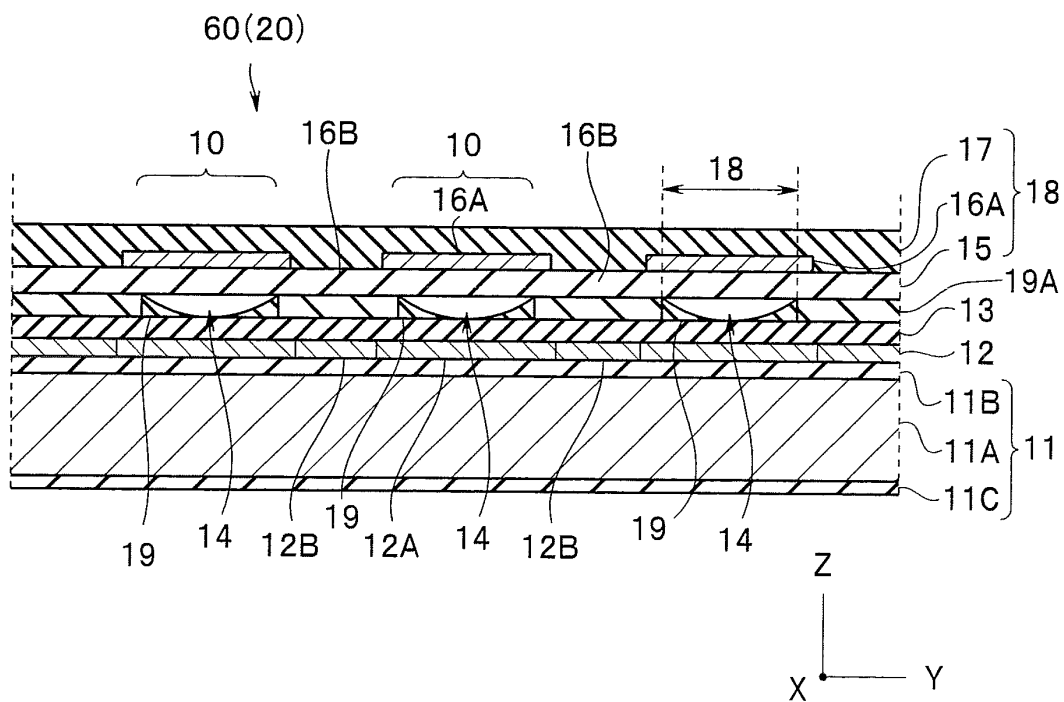


FIG.6

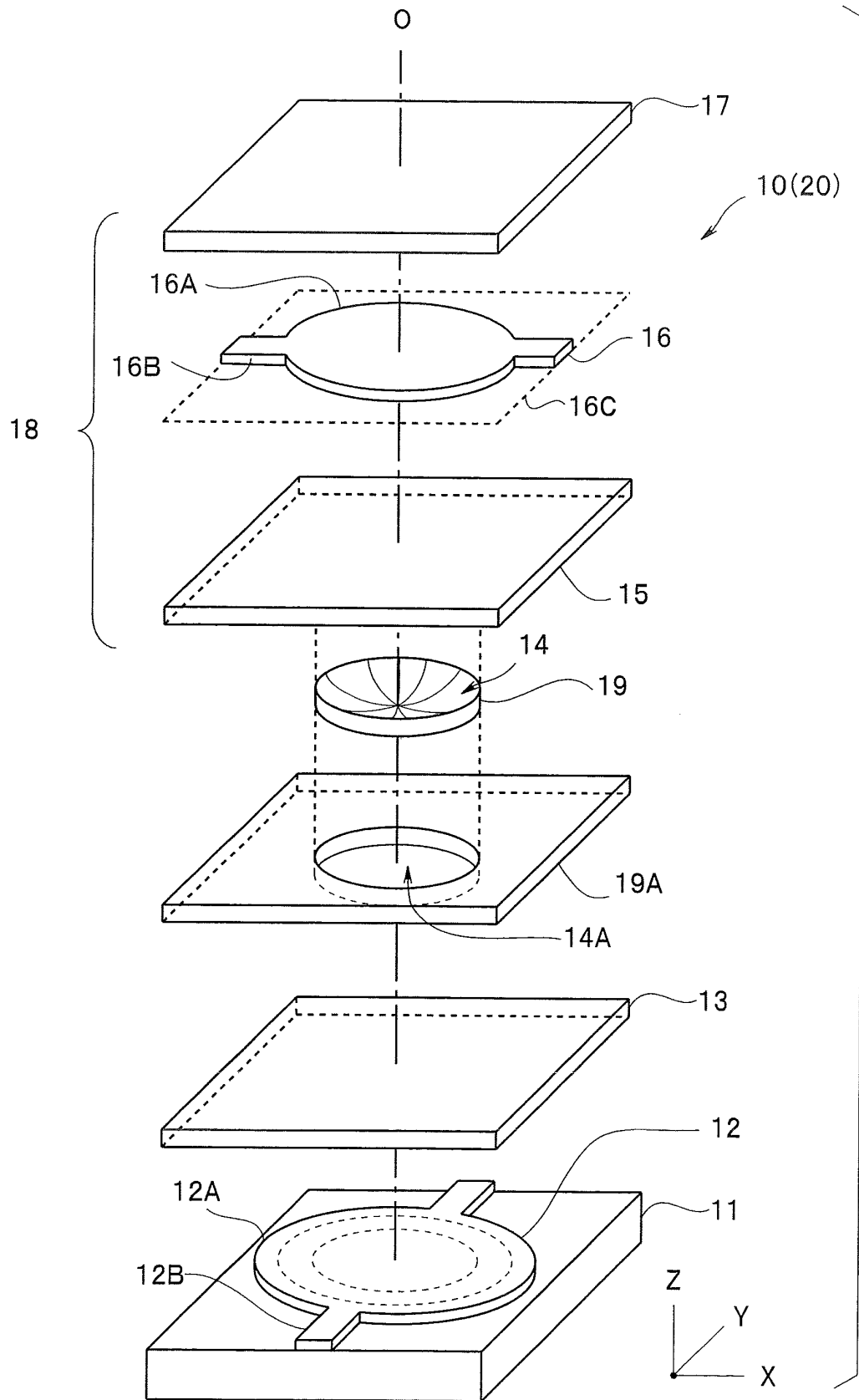


FIG.7A

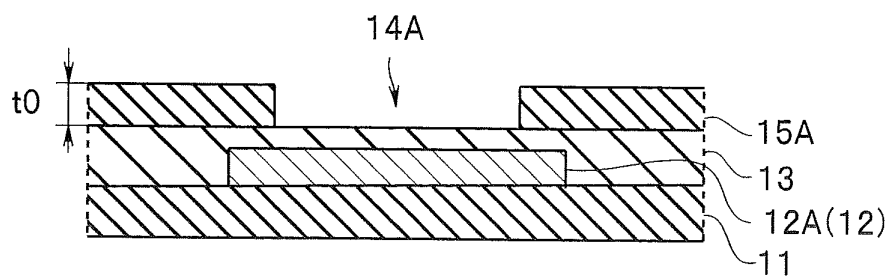


FIG.7B

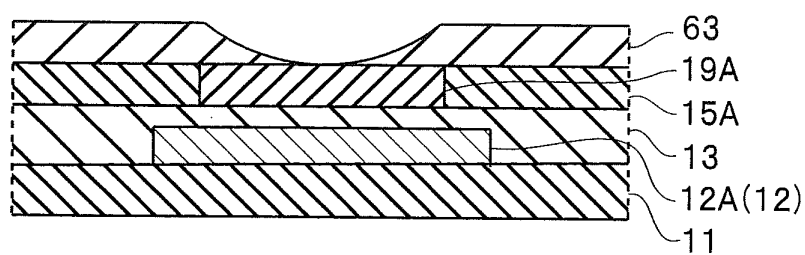


FIG.7C

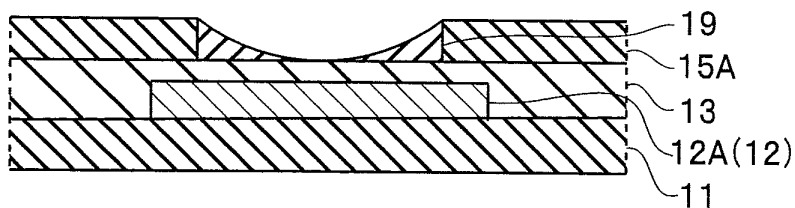


FIG.7D

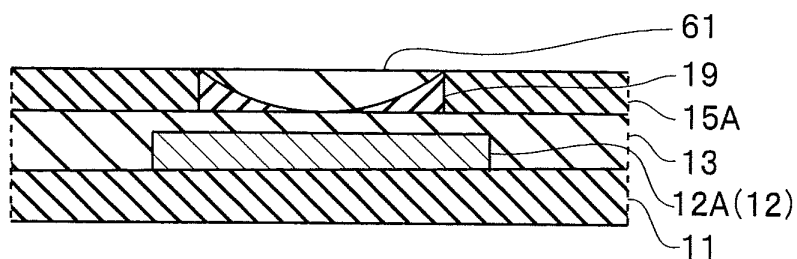


FIG.7E

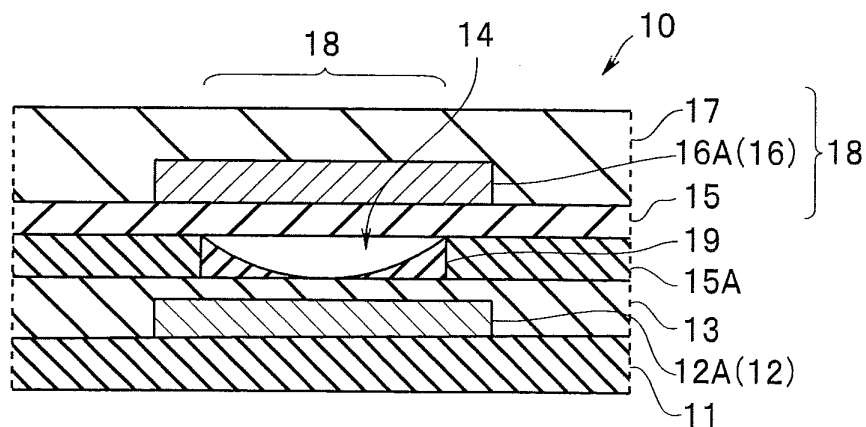


FIG.8A

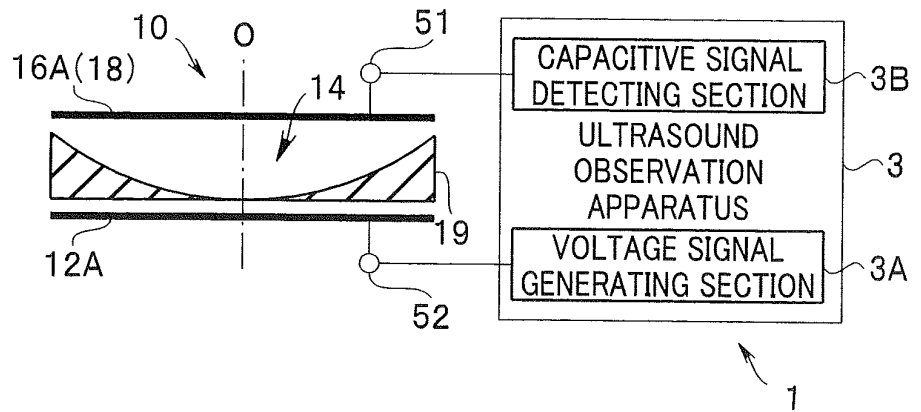


FIG.8B

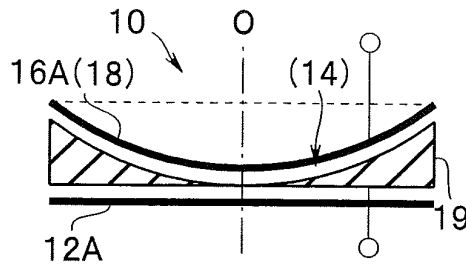


FIG.9A

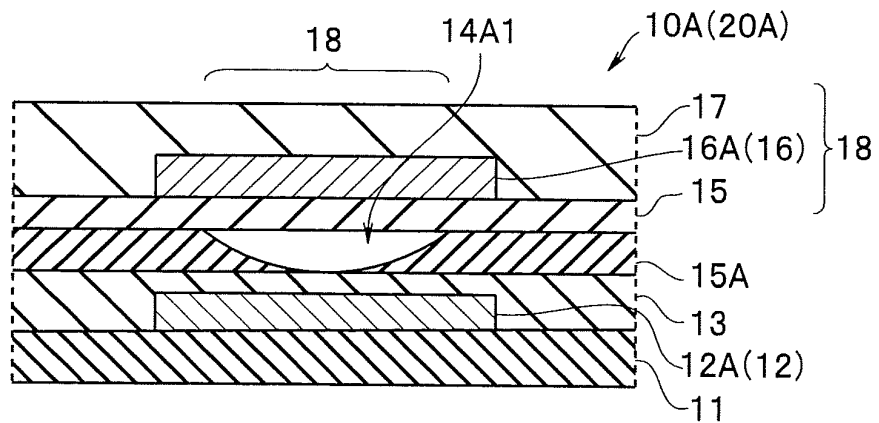


FIG.9B

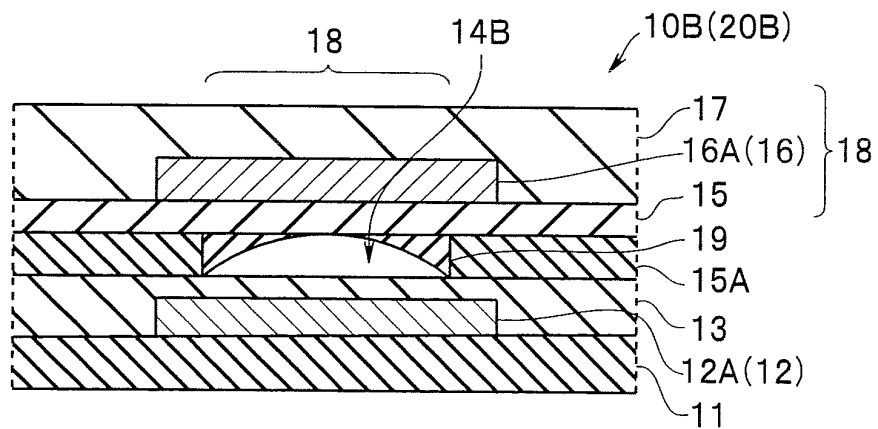


FIG.10A

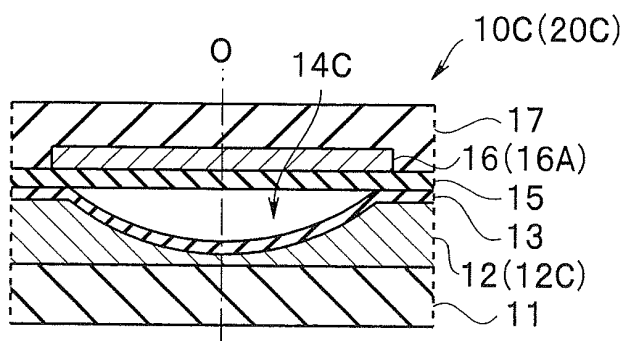


FIG.10B

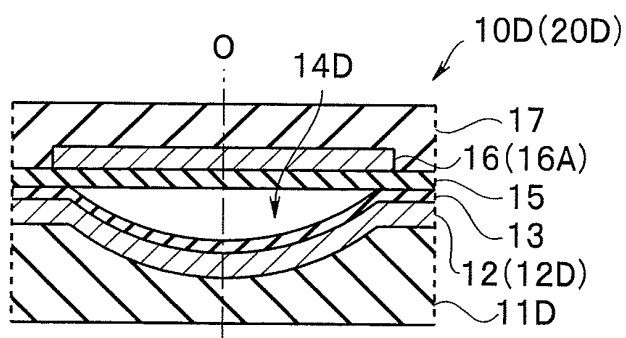


FIG.10C

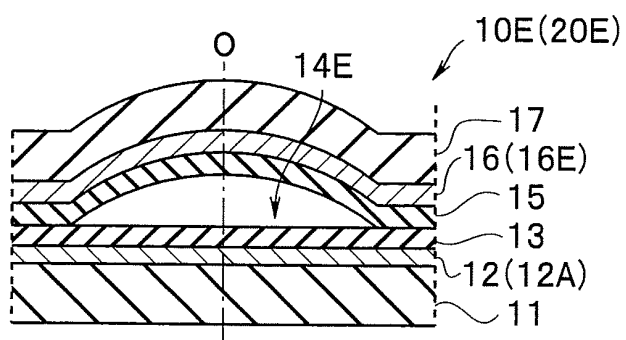
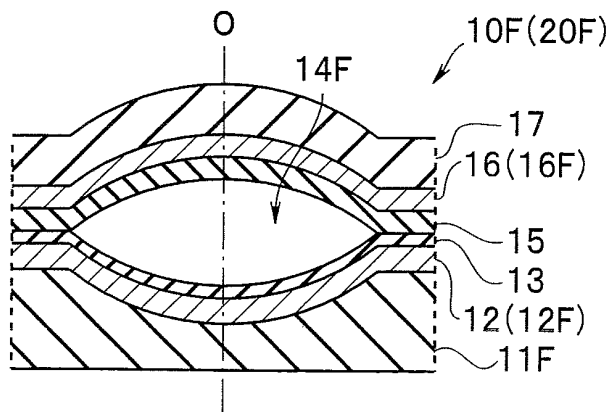


FIG.10D



REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2005510264 A [0004]
- WO 2009077961 A2 [0007]
- JP 2009055474 A [0008]

专利名称(译)	超声波振子元件和超声波内窥镜		
公开(公告)号	EP2775736B1	公开(公告)日	2018-09-05
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[标]申请(专利权)人(译)	奥林巴斯医疗株式会社 奥林巴斯株式会社		
申请(专利权)人(译)	奥林巴斯医疗系统股份有限公司. OLYMPUS CORPORATION		
当前申请(专利权)人(译)	OLYMPUS CORPORATION		
[标]发明人	MATSUMOTO KAZUYA KARAKI KAZUHISA HASEGAWA MAMORU WAKABAYASHI KATSUHIRO		
发明人	MATSUMOTO, KAZUYA KARAKI, KAZUHISA HASEGAWA, MAMORU WAKABAYASHI, KATSUHIRO		
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外部链接	Espacenet		

摘要(译)

超声换能器元件20包括多个静电电容型超声波单元10，每个超声波单元10具有下电极部分12A和膜18，膜18包括上电极部分16A，上电极部分16A经由在平面图中为圆形的腔14定向和设置，并且厚度为空腔14从腔18的中心部分朝向外圆周部分以弯曲的方式单调减小。

(Equation 1)

$$T(r) = TR \times [1 - J_0(2.4/R \times r)]$$