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Nakamura et al.

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(54) **ULTRASONIC TRANSDUCER, ULTRASONIC PROBE, AND ULTRASONIC EXAMINATION DEVICE**

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**

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H01L 41/08	(2006.01)
G01S 15/02	(2006.01)
A61B 8/00	(2006.01)
H01L 41/053	(2006.01)

(52) **U.S. Cl.**
CPC ***B06B 1/0644*** (2013.01); ***A61B 8/4444*** (2013.01); ***B06B 1/0622*** (2013.01); ***G01S 15/02*** (2013.01); ***H01L 41/053*** (2013.01); ***H01L 41/0825*** (2013.01)

(58) **Field of Classification Search**
CPC .. H01L 41/0825; H01L 41/092; H01L 41/098; G01S 15/02
USPC 367/140
See application file for complete search history.

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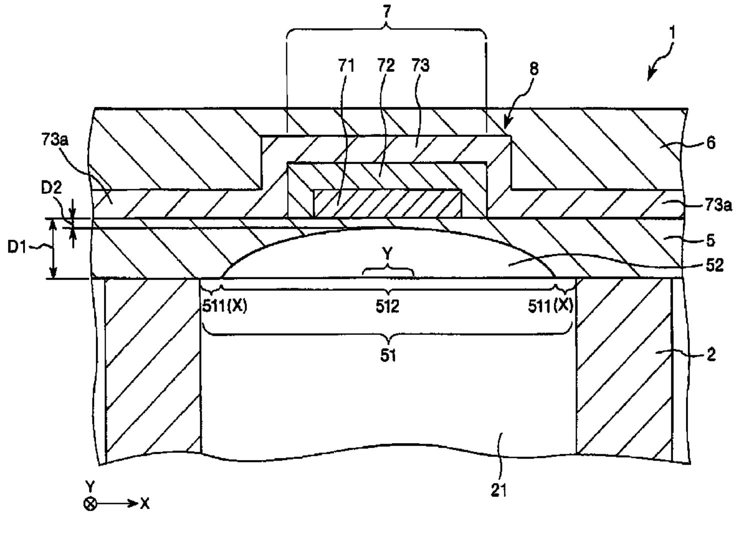
(57) **ABSTRACT**

An ultrasonic transducer includes a substrate, a supporting film disposed on the substrate, and a piezoelectric element disposed on the supporting film. The substrate includes an opening. The piezoelectric element is disposed on an area that overlaps the opening in a plan view in a thickness direction of the substrate. A thickness of the supporting film at an area that overlaps the piezoelectric element in a plan view of the supporting film is smaller than a thickness of the supporting film at a different area different from the area that overlaps the piezoelectric element.

12 Claims, 8 Drawing Sheets



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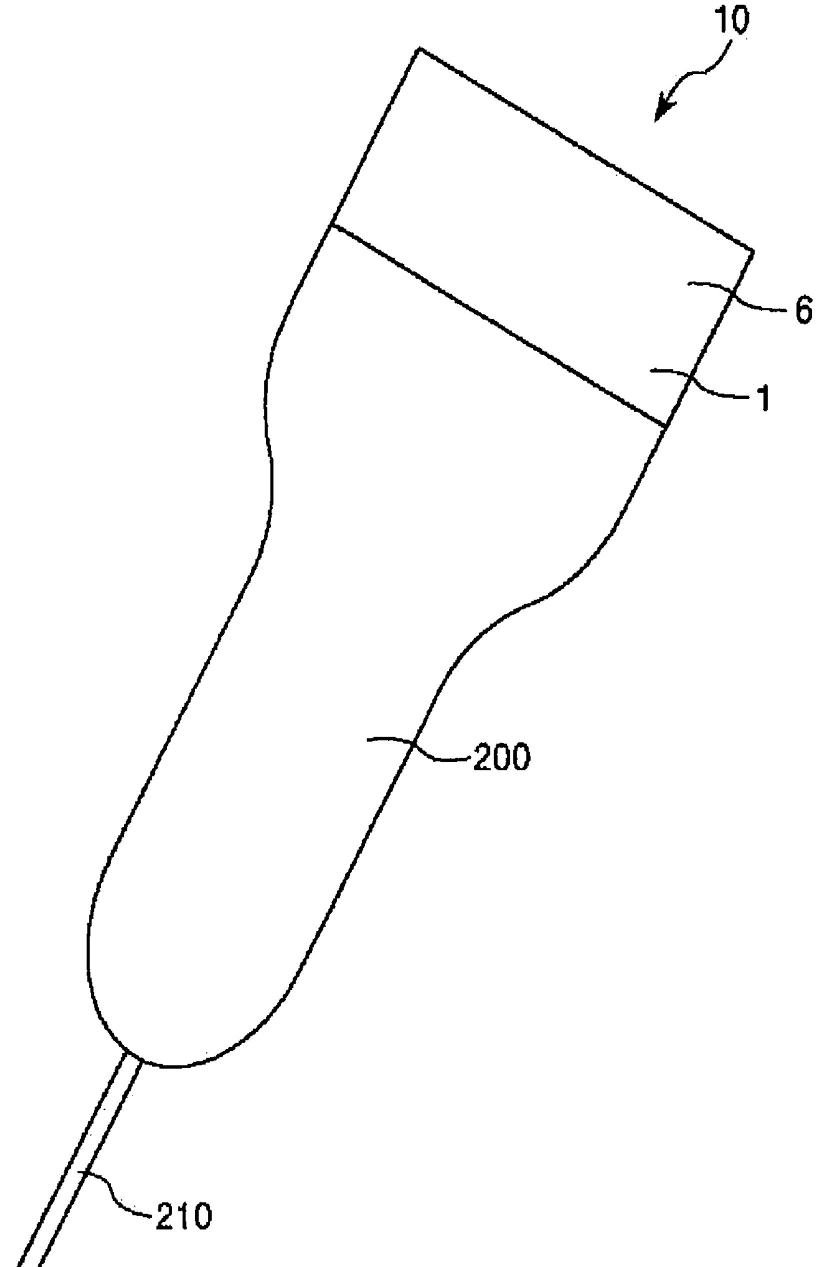


Fig. 1

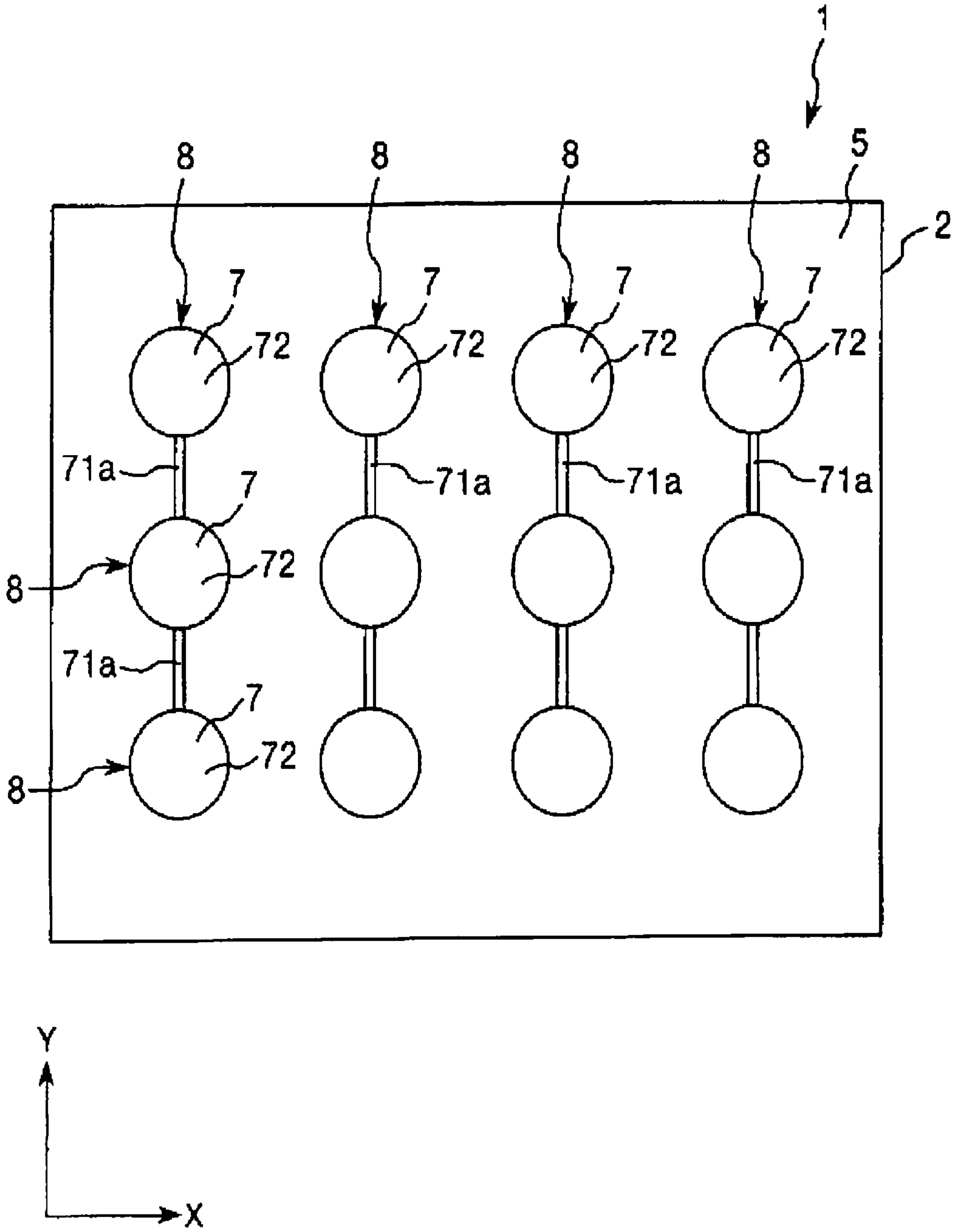
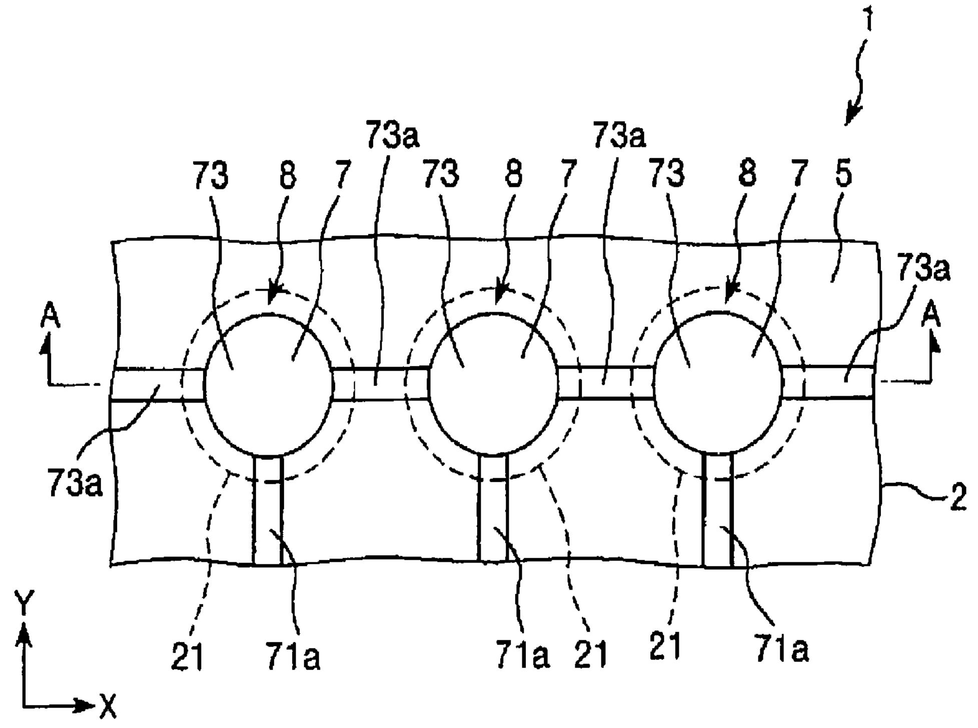


Fig. 2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73a
73a
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7
73
8
7
73
8
7
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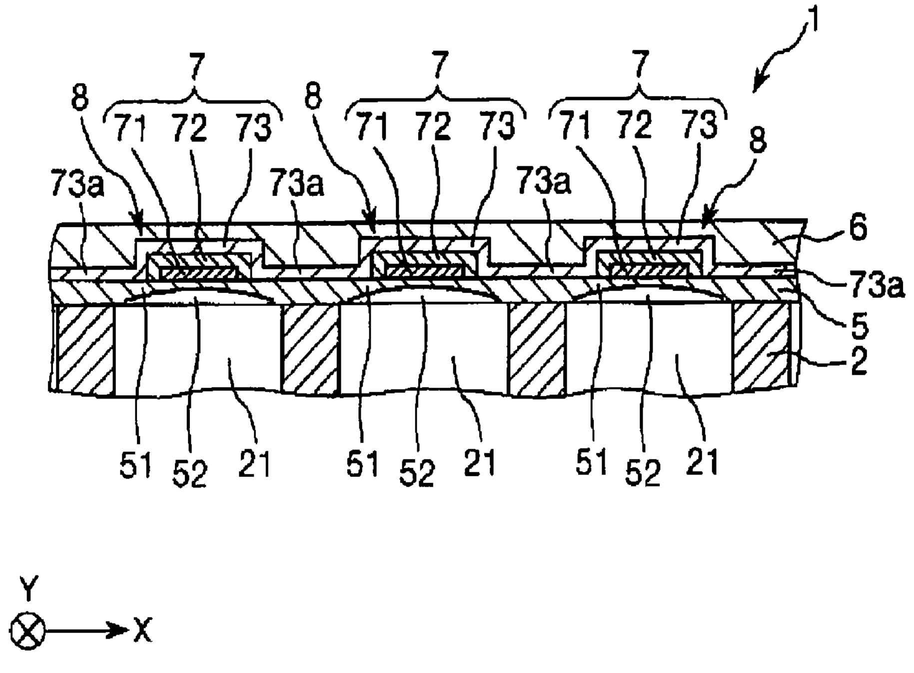
21
71a
71a
21
21
71a

Fig. 3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51
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21
51
52
21
51
52
21
Y
X

Fig. 4

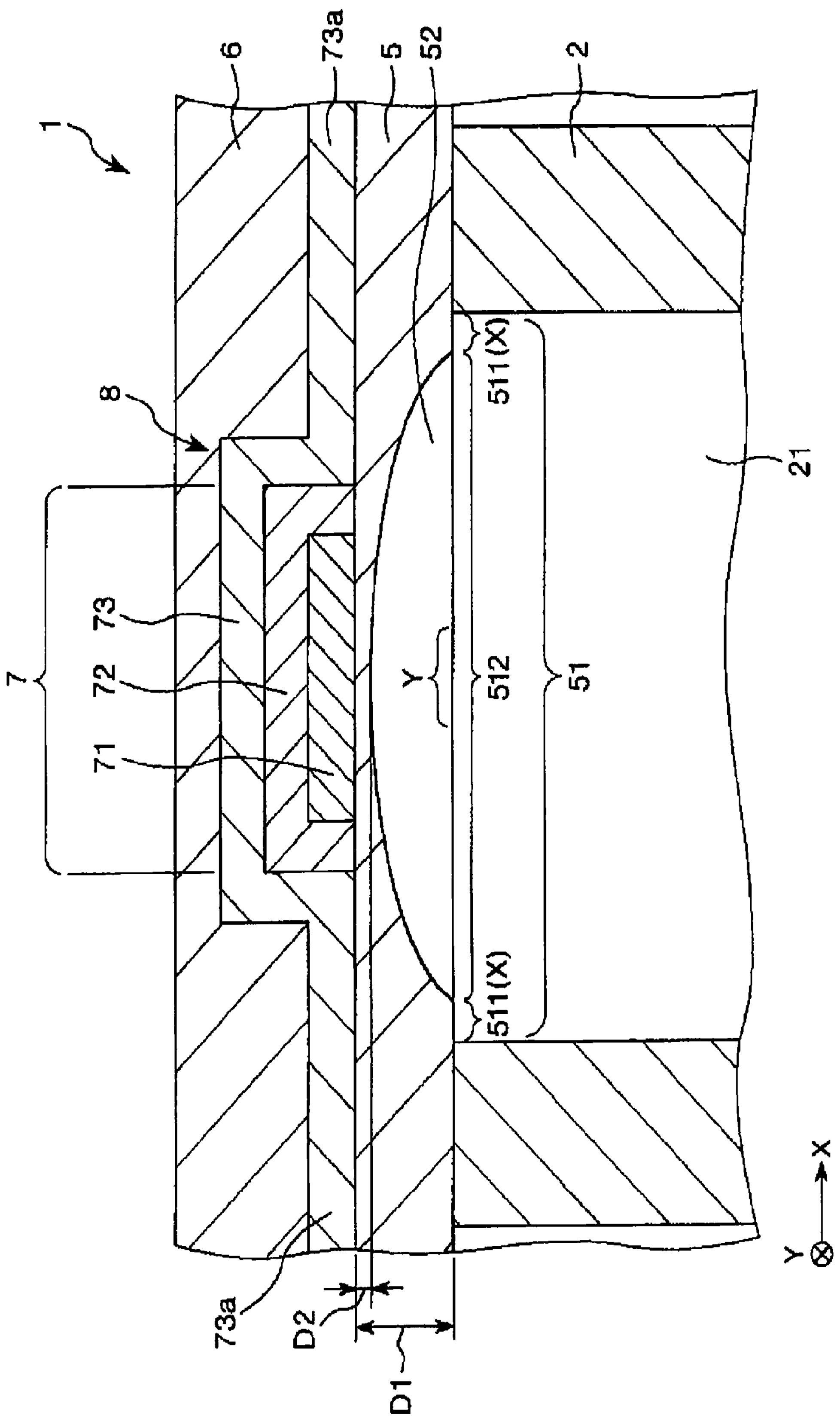


Fig. 5

Fig. 6A

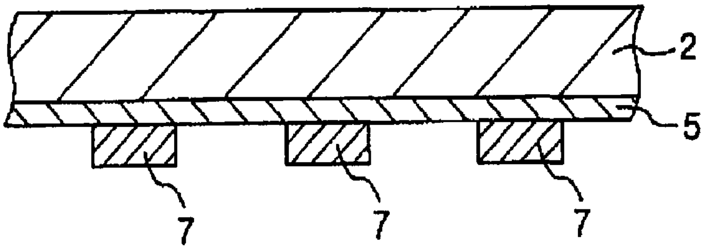


Fig. 6B

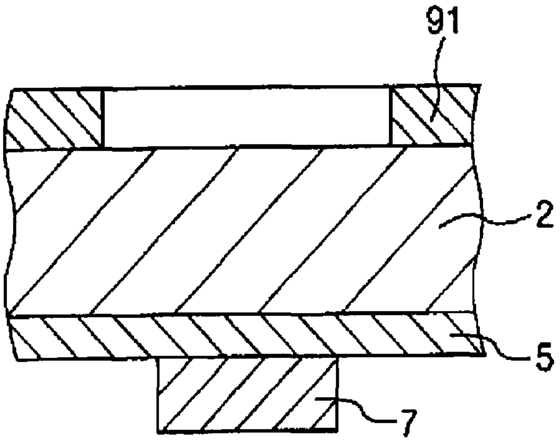


Fig. 6C

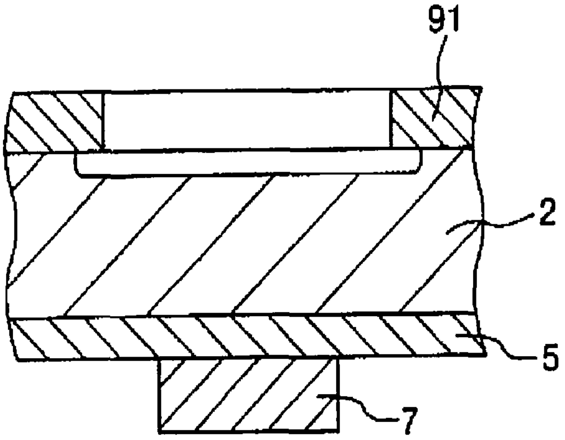


Fig. 6D

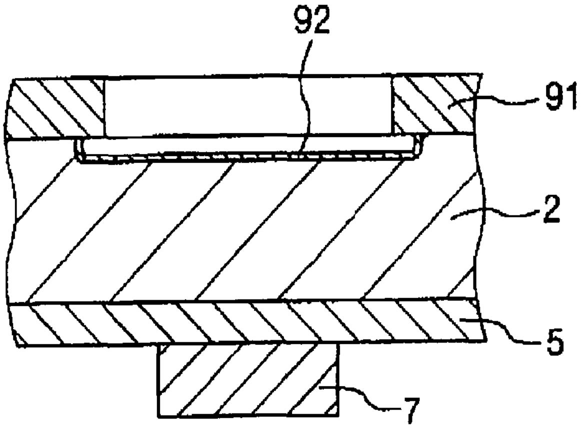


Fig. 7A

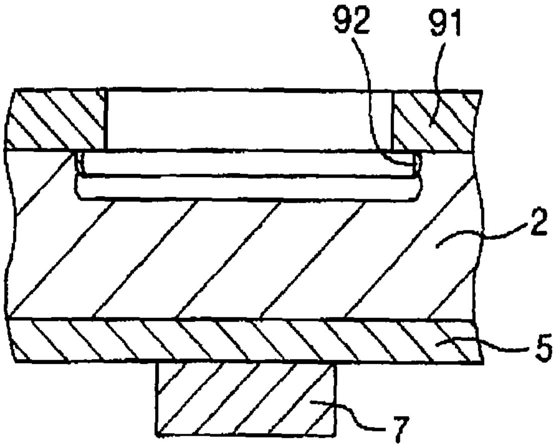


Fig. 7B

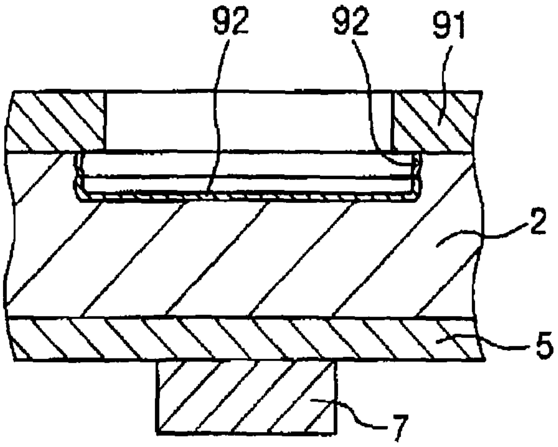
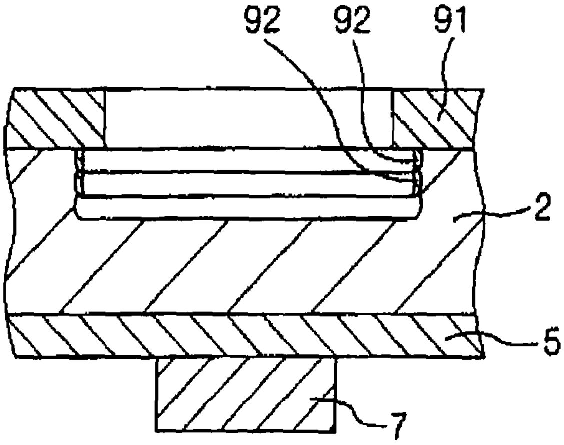


Fig. 7C



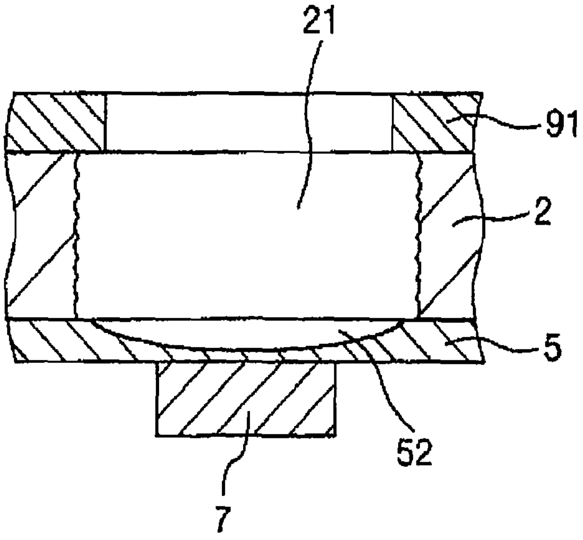


Fig. 8

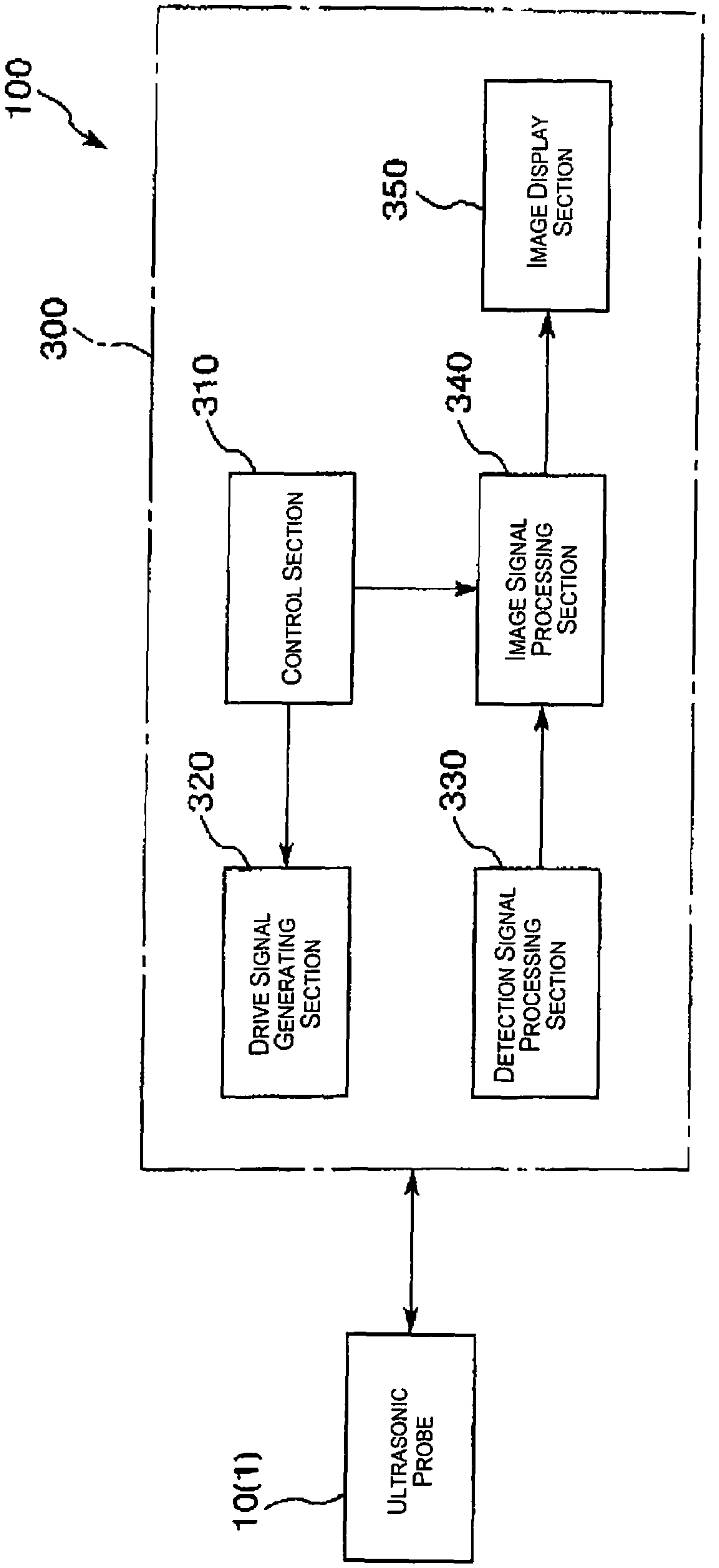

100
300
310
Control Section
320
Drive Signal Generating Section
330
Detection Signal Processing Section
340
Image Signal Processing Section
350
Image Display Section
10(1)
Ultrasonic Probe

Fig. 9

ULTRASONIC TRANSDUCER, ULTRASONIC PROBE, AND ULTRASONIC EXAMINATION DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation application of U.S. patent application Ser. No. 13/896,700 filed on May 17, 2013. This application claims priority to Japanese Patent Application No. 2012-115320 filed on May 21, 2012. The entire disclosures of U.S. patent application Ser. No. 13/896,700 and Japanese Patent Application No. 2012-115320 are hereby incorporated herein by reference.

BACKGROUND

Technical Field

The present invention relates to an ultrasonic transducer, an ultrasonic probe, and an ultrasonic examination device.

Background Technology

An ultrasonic transducer in which a plurality of ultrasonic elements are arranged in a matrix pattern has been known. This ultrasonic transducer includes a substrate that has a plurality of openings, a supporting film that is provided on the substrate so as to cover each of the openings, and a piezoelectric element that is provided on a part of the supporting film corresponding to each of the openings. A diaphragm is constructed by the part of the supporting film corresponding to the opening which is a part coinciding with the opening of the supporting film in a planar view. The ultrasonic element is constructed by the diaphragm and the piezoelectric element provided on the diaphragm. The thickness of the supporting film of the ultrasonic transducer, that is, the thickness of the part of the supporting film corresponding to the opening which coincides with the opening of the supporting film in a planar view is set to be uniform (for example, see Patent Document 1). In the ultrasonic transducer, the diaphragm is greatly deflected when ultrasonic waves are transmitted, and the diaphragm is slightly deflected when ultrasonic waves are received.

The well-known ultrasonic transducer, however, has a problem that the diaphragm is greatly deflected especially when ultrasonic waves are transmitted, which causes the stress to concentrate in the vicinity of an outer edge portion of the diaphragm and causes damage such as cracking or chipping. On the other hand, if the thickness of the diaphragm is increased to improve the strength of the diaphragm, the diaphragm will become hard to deflect. Then, especially when ultrasonic waves are received with the ultrasonic element, the deflection amount of the diaphragm will become smaller, which makes the stress generated in the piezoelectric element very small. Consequently, the level of a reception signal output from the piezoelectric element will be deteriorated. In other words, the characteristics of transmission and reception of ultrasonic waves, in particular, the sensitivity in reception will be deteriorated.

Japanese Laid-open Patent Publication No. 2000-23296 (Patent Document 1) is an example of the related art.

SUMMARY

According to one aspect of the invention, an ultrasonic transducer includes a substrate, a supporting film disposed on the substrate, and a piezoelectric element disposed on the supporting film. The substrate includes an opening. The piezoelectric element is disposed on an area that overlaps the opening in a plan view in a thickness direction of the substrate. A thickness of the supporting film at an area that overlaps the piezoelectric element in a plan view of the supporting film is smaller than a thickness of the supporting film at a different area different from the area that overlaps the piezoelectric element.

According to the aspect of the invention, the supporting film at an area that overlaps the opening includes a portion a thickness of which gradually increases as the portion approaches an area in which the supporting film overlaps the substrate in the plan view.

According to the aspect of the invention, the supporting film includes a surface facing the opening, and the surface has a curved concave surface.

According to the aspect of the invention, the supporting film at the area that overlaps the opening has a uniform thickness portion a thickness of which is uniform at an outer edge portion of the area that overlaps the opening.

According to the aspect of the invention, the uniform thickness portion is arranged along a whole circumference of the area that overlaps the opening in the plan view.

According to the aspect of the invention, the piezoelectric element is arranged on the supporting film such that the piezoelectric element does not overlap the uniform thickness portion.

According to the aspect of the invention, a thickness of the uniform thickness portion of the supporting film is D1, a thickness of the thinnest portion of the supporting film at the area that overlaps the opening is D2, and D2/D1 is within the range of 0.1 to 0.9.

According to the aspect of the invention, the ultrasonic transducer further includes an acoustic matching section disposed on the piezoelectric element.

According to the aspect of the invention, an acoustic impedance of the acoustic matching section is equal to an acoustic impedance of a living body.

According to the aspect of the invention, the ultrasonic transducer includes a piezoelectric array in which a plurality of piezoelectric elements including the piezoelectric element are arranged. The acoustic matching section is disposed on the piezoelectric array. The piezoelectric array includes a first piezoelectric element and a second piezoelectric element different from the first piezoelectric element. The acoustic matching section covers the first piezoelectric element and the second piezoelectric element. The acoustic matching section has a flat surface.

According to another aspect of the invention, an ultrasonic probe includes a case, and the ultrasonic transducer according to the aspect of the invention, which is accommodated in the case.

According to another aspect of the invention, an ultrasonic examination device includes an ultrasonic probe including a case, and the ultrasonic transducer according to the aspect of the invention, which is accommodated in the case, and a device main body including a signal processing section that is configured to conduct a signal processing based on a signal transmitted from the ultrasonic probe.

According to another aspect of the invention, an ultrasonic transducer includes a substrate, a supporting film disposed on the substrate, a piezoelectric element disposed on the supporting film, and an acoustic matching section disposed on the piezoelectric element. The substrate includes an opening. The piezoelectric element is disposed on an area that overlaps the opening in a plan view in a thickness direction of the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring now to the attached drawings which form a part of this original disclosure:

FIG. **1** is a perspective view showing an embodiment of an ultrasonic probe according to the invention;

FIG. **2** is a plan view showing an ultrasonic transducer of the ultrasonic probe shown in FIG. **1**;

FIG. **3** is a plan view enlarging a part of the ultrasonic transducer shown in FIG. **2**;

FIG. **4** is a sectional view along line A-A of FIG. **3**;

FIG. **5** is a sectional view enlarging a part of the ultrasonic transducer shown in FIG. **4**;

FIGS. **6**A-**6**D are sectional views explaining a method for manufacturing the ultrasonic transducer of the ultrasonic probe shown in FIG. **1**;

FIGS. **7**A-**7**C are sectional views explaining a method for manufacturing the ultrasonic transducer of the ultrasonic probe shown in FIG. **1**;

FIG. **8** is a sectional view explaining a method for manufacturing the ultrasonic transducer of the ultrasonic probe shown in FIG. **1**; and

FIG. **9** is a block diagram showing an embodiment of an ultrasonic examination device according to the invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

Hereinafter, the ultrasonic transducer, the ultrasonic probe, and the ultrasonic examination device of the invention will be explained in detail based on a preferred embodiment shown in the attached drawings.

Embodiment of Ultrasonic Transducer and Ultrasonic Probe

FIG. **1** is a perspective view showing an embodiment of an ultrasonic probe according to the invention. FIG. **2** is a plan view showing an ultrasonic transducer of the ultrasonic probe shown in FIG. **1**. FIG. **3** is a plan view enlarging a part of the ultrasonic transducer shown in FIG. **2**. FIG. **4** is a sectional view along line A-A of FIG. **3**. FIG. **5** is a sectional view enlarging a part of the ultrasonic transducer shown in FIG. **4**. FIG. **6**-FIG. **8** are sectional views explaining a method for manufacturing the ultrasonic transducer of the ultrasonic probe shown in FIG. **1**. Hereinafter, explanations will be made by describing the upper side in FIG. **3**-FIG. **7** as “upper”, the lower side as “lower”, the right side as “right”, and the left side as “left”.

In FIG. **2**, illustrations of parts and the like of an acoustic matching section, an upper electrode, a lower electrode, a conducting wire for an upper electrode, and a conducting wire for a lower electrode are omitted, and the ultrasonic transducer is schematically illustrated. In FIG. **3**, an illustration of the acoustic matching section is omitted. Further, in FIG. **6**-FIG. **8**, a piezoelectric element is schematically illustrated. Also, as shown in each drawing, an X axis and a Y axis orthogonal to each other are assumed. An X axis direction corresponds to an azimuth direction, and a Y axis direction corresponds to a slice direction.

As shown in FIG. **1**, an ultrasonic probe **10** has a case **200**, and an ultrasonic transducer **1** that is accommodated in the case **200**. The ultrasonic transducer **1** is disposed in a tip end portion of the case **200**. The ultrasonic probe **10** can be used as an ultrasonic probe for various kinds of ultrasonic examination devices such as an ultrasonic examination device **100** described below. In the present embodiment, a surface of the ultrasonic transducer **1**, that is, a surface of an acoustic matching section **6** described below is exposed outside. The acoustic matching section **6** serves as a protective layer of the ultrasonic probe **10** and the ultrasonic transducer **1**. Although the constituent material of the acoustic matching section **6** is not limited to a specific one, a material that is substantially similar to a living body with respect to the acoustic impedance, such as silicone rubber, is used. Here, it can be configured such that the surface of the acoustic matching section **6** is not exposed outside.

In conducting a test, the ultrasonic probe **10** is used by applying the surface of the acoustic matching section **6** to a living body as a test target. In such a case, when ultrasonic waves are sent out from the ultrasonic transducer **1** toward the acoustic matching section **6**, the ultrasonic waves pass through the acoustic matching section **6** and propagate through the living body. Then, the ultrasonic waves reflected on a predetermined part inside the living body pass through the acoustic matching section **6** and are input to the ultrasonic transducer **1**. Also, the ultrasonic probe **10** is electrically connected with a device main body **300** (see FIG. **9**), described below, of the ultrasonic examination device **100** through a cable **210**.

As shown in FIG. **2**-FIG. **5**, the ultrasonic transducer **1** has a substrate **2**, a plurality of (twelve in the configuration shown in the drawing) ultrasonic elements (ultrasonic vibrators) **8** that are provided on the substrate **2** so as to transmit and receive ultrasonic waves, and the acoustic matching section **6** that is provided on the substrate **2** on the side of the ultrasonic elements **8** so as to cover each of the ultrasonic elements **8**. Although the shape of the substrate **2** is not limited to a specific one, it forms a quadrangle in a planar view in the configuration shown in the drawing. Also, as another shape of the substrate **2** in a planar view, another polygon such as a pentagon or a hexagon, a circle, or an ellipse can be listed, for example. Although the constituent material of the substrate **2** is not limited to a specific one, a material for forming a semiconductor such as silicon (Si) is used, for example. Consequently, it can be processed easily by etching or the like.

The ultrasonic element **8** is constructed of a diaphragm **51** and a piezoelectric body (piezoelectric element) **7**, and each of the ultrasonic elements **8** is arranged on the substrate **2** in a matrix pattern. In other words, the plurality of (four in the configuration shown in the drawing) ultrasonic elements **8** are arranged in parallel along the X axis direction, and the plurality of (three in the configuration shown in the drawing) ultrasonic elements **8** are arranged in parallel along the Y axis direction. Although the shape of the piezoelectric body **7** is not limited to a specific one, it forms a circle in a planar view in the configuration shown in the drawing. Also, as another shape of the piezoelectric body **7** in a planar view, a quadrangle (square, rectangle), a polygon such as a pentagon or a hexagon, or an ellipse can be listed, for example. Incidentally, the piezoelectric body **7** and the wiring thereof will be described below.

An opening **21** for forming the diaphragm **51** of the ultrasonic element **8** is formed in a part of the substrate **2** corresponding to each of the ultrasonic elements **8**. Although the shape of the opening **21** is not limited to a specific one, it forms a circle in a planar view in the configuration shown in the drawing. Also, as another shape of the opening **21** in a planar view, a quadrangle (square, rectangle), a polygon such as a pentagon or a hexagon, or an ellipse can be listed, for example.

A supporting film **5** is formed on the substrate **2**, and each of the openings **21** is covered with the supporting film **5**. The diaphragm **51** is constructed by a part of the supporting film **5** corresponding to the opening which is a part (region) covering the opening **21**, that is, a part coinciding with (part overlapping with) the opening **21** of the supporting film **5** in a planar view. The piezoelectric body **7** is provided on the diaphragm **51**.

Although the constituent material of the supporting film **5** is not limited to a specific one, the supporting film **5** is constructed by a layered body (two-layer structure) of an SiO_2 film and a ZrO_2 layer, or an SiO_2 film, for example. In a case where the substrate **2** is an Si substrate, the SiO_2 layer can be formed by conducting a thermal oxidation treatment to the surface of the substrate **2**. The ZrO_2 layer can be formed on the SiO_2 layer, for example, by a technique such as sputtering. Here, the ZrO_2 layer is a layer for preventing Pb that constitutes PZT from diffusing into the SiO_2 layer when PZT is used as a piezoelectric film **72** of the piezoelectric body **7**, for example. The piezoelectric film **72** of the piezoelectric body **7** will be described below. The ZrO_2 layer also has an effect such as an effect of improving deflection efficiency with respect to deformation of the piezoelectric film **72**.

As shown in FIG. **5**, the piezoelectric body **7** has a lower electrode **71** formed on the diaphragm **51** (the supporting film **5**), the piezoelectric film **72** formed on the lower electrode **71**, and an upper electrode **73** formed on the piezoelectric film **72**. Also, a conducting wire for a lower electrode **71***a* is connected with the lower electrode **71**, and the conducting wire for a lower electrode **71***a* extends along the Y axis direction on the supporting film **5** as shown in FIG. **3**, for example. The conducting wire for a lower electrode **71***a* serves as a common conducting wire of each ultrasonic element **8** arranged in the Y axis direction. More specifically, as shown in FIG. **3** and FIG. **4**, the conducting wire for a lower electrode **71***a* is connected with the lower electrodes **71** of two adjacent ultrasonic elements **8** arranged in the Y axis direction. With this configuration, the assembly of the ultrasonic elements **8** arranged in the Y axis direction can be driven independently.

A conducting wire for an upper electrode **73***a* is connected with the upper electrode **73**, and the conducting wire for an upper electrode **73***a* extends along the X axis direction on the supporting film **5** as shown in FIG. **3**, for example. The conducting wire for an upper electrode **73***a* serves as a common conducting wire of each ultrasonic element **8** arranged in the X axis direction. More specifically, as shown in FIG. **3**, the conducting wire for an upper electrode **73***a* is connected with the upper electrodes **73** of two adjacent ultrasonic elements **8** arranged in the X axis direction, and is connected to the GND, for example, at the end portion thereof. In this manner, the upper electrode **73** of each ultrasonic element **8** is earthed. Alternatively, contrary to the above, the conducting wire for a lower electrode **71***a* can be connected to the GND.

The constituent materials of the lower electrode **71**, the upper electrode **73**, the conducting wire for a lower electrode **71***a*, and the conducting wire for an upper electrode **73***a* are not limited to specific ones as long as they have conductive properties, respectively. For example, various kinds of metal materials can be used. Also, the lower electrode **71**, the upper electrode **73**, the conducting wire for a lower electrode **71***a*, and the conducting wire for an upper electrode **73***a* can be single layers, respectively, or can be layered bodies in which a plurality of layers are laminated, respectively. As specific examples, for example, a Ti/Ir/Pt/Ti layered film can be used as the lower electrode **71** and the conducting wire for a lower electrode **71***a*, respectively, and an Ir film can be used as the upper electrode **73** and the conducting wire for an upper electrode **73***a*, respectively.

The piezoelectric film **72** is made by forming PZT (lead zirconate titanate) into a film shape, for example. In the present embodiment, PZT is used as the piezoelectric film **72**. However, any material can be used as long as it is a material that can contract (expand or contract) in an in-plane direction by applying a voltage thereto. For example, lead titanate ($PbTiO_3$), lead zirconate ($PbZrO_3$), lead lanthanum titanate ((Pb, La) TiO_3), or the like can be used as well as PZT.

In the ultrasonic element **8**, for example, when a voltage is applied between the lower electrode **71** and the upper electrode **73** by the device main body **300** (see FIG. **9**) through the cable **210**, the piezoelectric film **72** expands or contracts in the in-plane direction. In this instance, a surface of the piezoelectric film **72** is attached to the supporting film **5** through the lower electrode **71**, and the upper electrode **73** is formed on the other surface thereof. Here, since any other layer is not formed on the upper electrode **73**, the supporting film **5** side of the piezoelectric film **72** does not easily expand or contract, while the upper electrode **73** side of the piezoelectric film **72** easily expands or contracts. Therefore, when a voltage is applied to the piezoelectric film **72**, deflection that causes projection occurs on the opening **21** side, which results in deflection of the first diaphragm **51**. Consequently, when an alternating voltage is applied to the piezoelectric film **72**, the diaphragm **51** vibrates with respect to the film thickness direction, and this vibration of the diaphragm **51** transmits (sends) ultrasonic waves. In transmission of such ultrasonic waves, an alternating voltage, whose frequency is equal to the resonance frequency of the ultrasonic element **8**, or is close to the resonance frequency and is smaller than the resonance frequency, is applied to the piezoelectric film **72**, and the ultrasonic element **8** is resonantly driven. With this, the diaphragm **51** is greatly deflected, so that ultrasonic waves can be transmitted with high output.

In receiving ultrasonic waves with the ultrasonic element **8**, when ultrasonic waves are input to the diaphragm **51**, the diaphragm **51** vibrates with respect to the film thickness direction. In the ultrasonic element **8**, this vibration of the diaphragm **51** causes a potential difference between the surface of the piezoelectric film **72** on the lower electrode **71** side and the surface of the piezoelectric film **72** on the upper electrode **73**, and a reception signal (detection signal) (current) is output from the upper electrode **73** and the lower electrode **71** in response to the displacement amount of the piezoelectric film **72**. This signal is transmitted to the device main body **300** (see FIG. **9**) through the cable **210**, and predetermined signal processing or the like is conducted based on the signal. Then, in the device main body **300**, an ultrasonic image (electronic image) is formed and displayed. In the ultrasonic probe **10**, planar waves of ultrasonic waves can be transmitted in a desired direction by delaying and differentiating the timing of transmission of ultrasonic waves from each ultrasonic element **8** arranged in parallel along the X axis direction.

As shown in FIG. **5**, in the ultrasonic transducer **1**, a thickness of the part of the supporting film corresponding to the opening which coincides with the opening **21** of the supporting film **5** in a planar view, that is, a thickness of a central portion of the diaphragm **51** is smaller than a thickness of an outer edge portion of the diaphragm **51**. Here, the outer edge portion of the part of the supporting film corresponding to the opening is an annular region X having a predetermined width from an outer circumferential end of the part of the supporting film corresponding to the opening toward the inside of the part of the supporting film corresponding to the opening, that is, toward the center of gravity in a planar view. The central portion of the part of the supporting film corresponding to the opening is a region Y having a predetermined area that includes the position of the center of gravity of the part of the supporting film corresponding to the opening except the region X (outer edge portion).

In the present embodiment, the diaphragm **51** has a uniform thickness portion **511** whose thickness is uniform in the outer edge portion thereof. The uniform thickness portion **511** is provided along the circumference of the diaphragm **51**. In other words, the uniform thickness portion **511** has an annular shape in a planar view. The diaphragm **51** also has a gradually increasing thickness portion **512** whose thickness gradually increases from the center of gravity (the central portion) of the diaphragm **51** toward the outer edge portion thereof. A concave portion **52** having a curved surface curved in a bowl shape (curved concave surface) is formed in a lower surface of the diaphragm **51**. With this configuration, the strength of the outer edge portion of the diaphragm **51**, that is, the strength of the uniform thickness portion **511** is increased, and the gradually increasing thickness portion **512** of the diaphragm **51**, in particular, the central portion side of the gradually increasing thickness portion **512** becomes easy to deflect. Consequently, damage such as cracking or chipping of the diaphragm **51** can be prevented from occurring while having good characteristics of transmission and reception of ultrasonic waves.

More specifically, even if the diaphragm **51** is greatly deflected in transmission and reception of ultrasonic waves, especially, in transmission of ultrasonic waves due to the resonant drive of the ultrasonic element **8**, damage such as cracking or chipping can be prevented from occurring in the vicinity of the outer edge portion of the diaphragm **51**. Further, since the central portion of the diaphragm **51** becomes easy to deflect locally, the deflection amount of the piezoelectric body **7** can be increased in transmission and reception of ultrasonic waves, especially, in reception of ultrasonic waves in which the deflection amount of the diaphragm **51** is small. Consequently, large stress is generated in the piezoelectric body **7**, and the level of a reception signal output from the piezoelectric body **7** can be improved. In other words, the sensitivity in reception of ultrasonic waves can be improved. Further, the piezoelectric body **7** is provided closer to the central portion compared to the uniform thickness portion **511** on the diaphragm **51**. Consequently, the sensitivity in reception of ultrasonic waves can be improved more securely.

Here, the size of the diaphragm **51** (the supporting film **5**) is not limited to a specific one, and is determined based on various conditions. However, when the thickness of the uniform thickness portion **511** (outer edge) of the diaphragm **51** is D1 and the thickness of the position of the center of gravity (center) of the diaphragm **51** in a planar view is D2, D2/D1 is preferably within the range of 0.1 to 0.9. With this configuration, damage such as cracking or chipping can be prevented from occurring in the vicinity of the outer edge portion of the diaphragm **51** more securely, and the sensitivity in reception of ultrasonic waves can be improved more securely.

Preferably, the thickness D1 of the uniform thickness portion **511** (outer edge) of the diaphragm **51** is within the range of 0.4 μm to 1.5 μm. With this configuration, damage such as cracking or chipping can be prevented from occurring in the vicinity of the outer edge portion of the diaphragm **51** more securely. Preferably, the thickness D2 of the position of the center of gravity of the diaphragm **51** is within the range of 0.15 μm to 1.35 μm. With this configuration, the sensitivity in reception of ultrasonic waves can be improved more securely.

Further, when the area of the uniform thickness portion **511** of the diaphragm **51** is S1 and the area of the gradually increasing thickness portion **512** is S2 in a planar view, S1/S2 is preferably within the range of 0.02 to 0.25. With this configuration, damage such as cracking or chipping can be prevented from occurring in the vicinity of the outer edge portion of the diaphragm **51** more securely, and the sensitivity in reception of ultrasonic waves can be improved more securely. In the present embodiment, the diaphragm **51** has the uniform thickness portion **511**. However, the uniform thickness portion **511** can be omitted.

Next, explanations will be made on an example of a method for processing the substrate **2** and the supporting film **5** in a method for manufacturing the ultrasonic transducer **1**, that is, a method for forming each opening **21** of the substrate **2** and each concave portion **52** of the supporting film **5** (the diaphragm **51**). Here, as one example, a case where the substrate **2** is composed of Si and the supporting film **5** is composed of SiO_2 will be described. First, as shown in FIG. **6**(*a*), a structure including the substrate **2** with unformed opening **21**, the supporting film **5** with unformed concave portion **52** above the substrate **2**, and the piezoelectric body **7** above the supporting film **5** is manufactured. As a method for manufacturing this structure, since a conventionally known method or the like can be used, the explanations thereof will be omitted.

Next, each opening **21** is formed in the substrate **2** and each concave portion **52** is formed in the supporting film **5** by conducting processing to parts of the substrate **2** and the supporting film **5** corresponding to the piezoelectric body **7**, respectively, so as to form each diaphragm **51**. Since a method for forming each opening **21** is similar and a method for forming each concave portion **52** is similar, a method for forming one of the openings **21** and a method for forming one of the concave portions **52** will be explained hereinafter as representatives.

First, as shown in FIG. **6**(*b*), a resist film **91** is formed on the upper surface of the substrate **2** except the part in which the opening **21** of the substrate **2** is formed. Next, as shown in FIGS. **6**(*c*)-**6**(*d*), FIGS. **7**(*a*)-**7**(*c*), and FIG. **8**, the opening **21** is formed by the Bosch process (cycle etching) in which an etching process and formation of a protective film **92** are repeated alternately a plurality of times with respect to the substrate **2** using the resist film **91** as a mask. For this Bosch process, an inductively coupled (ICP) reactive ion etching apparatus is used. More specifically, inductively coupled reactive ion etching is conducted to the substrate **2** using an inductively coupled reactive ion etching apparatus in the etching process, and subsequently, the protective film **92** is formed in the substrate **2** using the inductively coupled reactive ion etching apparatus. In FIG. **6** and FIG. **7**, a case where the etching process is conducted three times and the formation of the protective film **92** is conducted twice is illustrated. However, the numbers of times of the etching process and the formation of the protective film **92** are not limited to these numbers, respectively, and the actual numbers of times are larger than these numbers.

Here, in the etching process, mixed gas of SF_6 and O_2 is used as processing gas, for example. The flow rate of the processing gas in the etching process is not limited to a specific one, and is set as appropriate based on various conditions. However, for example, it is preferable to set within the range of 100 sccm to 1000 sccm, and it is more preferable to set within the range of 200 sccm to 700 sccm.

The processing time of the etching process is not limited to specific one, and is set as appropriate based on various conditions. However, for example, it is preferable to set within the range of 1 second to 20 seconds. The coil power of the inductively coupled plasma in the etching process is not limited to specific one, and is set as appropriate based on various conditions. However, for example, it is preferable to set within the range of 300 W to 3000 W.

Also, in forming the protective film **92**, mixed gas of C_4F_8 and O_2 is used as processing gas, for example. The flow rate of the processing gas in forming the protective film **92** is not limited to a specific one, and is set as appropriate based on various conditions. However, for example, it is preferable to set within the range of 50 sccm to 600 sccm.

The time for forming the protective film **92** is not limited to specific one, and is set as appropriate based on various conditions. However, for example, it is preferable to set within the range of 0.5 second to 10 seconds. The coil power of the inductively coupled plasma in forming the protective film **92** is not limited to specific one, and is set as appropriate based on various conditions. However, for example, it is preferable to set within the range of 100 W to 2500 W. Incidentally, by composing the substrate **2** of Si, the opening **21** can be formed so as to be perpendicular to the upper surface and the lower surface of the substrate **2**.

Next, as shown in FIG. **8**, the concave portion **52** is formed by the Bosch process in which an etching process and formation of the protective film **92** are repeated alternately a plurality of times with respect to the supporting film **5** using the resist film **91** as a mask. For this Bosch process, an inductively coupled (ICP) reactive ion etching apparatus is used. More specifically, inductively coupled reactive ion etching is conducted to the supporting film **5** using an inductively coupled reactive ion etching apparatus in the etching process, and subsequently, a protective film which is not shown in the drawing is formed in the supporting film **5** using the inductively coupled reactive ion etching apparatus.

Here, in the etching process, mixed gas of SF_6 and O_2 is used as processing gas, for example. The flow rate of the processing gas in the etching process is not limited to a specific one, and is set as appropriate based on various conditions. However, for example, it is preferable to set within the range of 100 sccm to 1000 sccm, and it is more preferable to set within the range of 200 sccm to 700 sccm.

The processing time of the etching process is not limited to specific one, and is set as appropriate based on various conditions. However, for example, it is preferable to set within the range of 1 second to 20 seconds. The coil power of the inductively coupled plasma in the etching process is not limited to specific one, and is set as appropriate based on various conditions. However, for example, it is preferable to set within the range of 300 W to 3000 W.

Also, in forming the above-described protective film, mixed gas of C_4F_8 and O_2 is used as processing gas, for example. The flow rate of the processing gas in forming the protective film is not limited to a specific one, and is set as appropriate based on various conditions. However, for example, it is preferable to set within the range of 50 sccm to 600 sccm.

The time for forming the protective film is not limited to specific one, and is set as appropriate based on various conditions. However, for example, it is preferable to set within the range of 0.5 second to 10 seconds. The coil power of the inductively coupled plasma in forming the protective film is not limited to specific one, and is set as appropriate based on various conditions. However, for example, it is preferable to set within the range of 100 W to 2500 W. Incidentally, by composing the supporting film **5** of SiO_2, the concave portion **52** having a curved surface curved in a bowl shape is formed.

Next, the resist film **91** is removed. As described above, the ultrasonic transducer **1** is manufactured. Incidentally, the shape of the concave portion **52** such as the degree of curving of the concave portion **52** can be set as appropriate by adjusting the selected ratio of Si/SiO_2 or the like. Further, formation or non-formation of the uniform thickness portion **511**, and the size of the uniform thickness portion **511** and the like in a case of forming the uniform thickness portion **511** can be set as appropriate by adjusting the flow rate of the processing gas in the etching process, the processing time of the etching process, the coil power of the inductively coupled plasma in the etching process, the flow rate of the processing gas in forming the protective film, the time for forming the protective film, the coil power of the inductively coupled plasma in forming the protective film, or the like. The ultrasonic probe **10** described above can be applied to an ultrasonic examination device in a preferred manner.

Next, an example of the conditions of each process in a case where the uniform thickness portion **511** is formed in the supporting film **5**, and an example of the conditions of each process in a case where the uniform thickness portion **511** is not formed in the supporting film **5** will be described. These conditions are ones in a case where the thickness of the substrate **2** is 200 μm, Si is used as the constituent material of the substrate **2**, and SiO_2 is used as the constituent material of the supporting film **5**, respectively.

(1) The Case where the Uniform Thickness Portion **511** is Formed in the Supporting Film **5**

First, in the etching process to the substrate **2**, mixed gas of SF_6 and O_2 is used as the processing gas, the flow rate of the processing gas is 450 sccm, and the coil power is 2500 W. Also, in forming the protective film **92** in the substrate **2**, mixed gas of C_4F_8 and O_2 is used as the processing gas, the flow rate of the processing gas is 150 sccm, and the coil power is 1500 W. The processing time of the etching process is 10 seconds, and the time for forming the protective film **92** is 6 seconds. The etching process and the formation of the protective film **92** are conducted alternately for 36 minutes in total.

Next, in the etching process to the supporting film **5**, mixed gas of SF_6 and O_2 is used as the processing gas, the flow rate of the processing gas is 450 sccm, and the coil power is 2500 W. Also, in forming the protective film **92** in the supporting film **5**, mixed gas of C_4F_8 and O_2 is used as the processing gas, the flow rate of the processing gas is 150 sccm, and the coil power is 1500 W. The processing time of the etching process is 10 seconds, and the time for forming the protective film **92** is 6 seconds. The etching process and the formation of the protective film **92** are conducted alternately for 14 minutes 24 seconds in total. With that, the process is finished.

(2) The Case where the Uniform Thickness Portion **511** is not Formed in the Supporting Film **5**

First, in the etching process to the substrate **2**, mixed gas of SF_6 and O_2 is used as the processing gas, the flow rate of the processing gas is 450 sccm, and the coil power is 2500 W. Also, in forming the protective film **92** in the substrate **2**, mixed gas of C_4F_8 and O_2 is used as the processing gas, the flow rate of the processing gas is 150 sccm, and the coil power is 1500 W. The processing time of the etching process is 10 seconds, and the time for forming the protective film **92** is 6 seconds. The etching process and the formation of the protective film **92** are conducted alternately for 36 minutes in total.

Next, in the etching process to the supporting film **5**, mixed gas of SF_6 and O_2 is used as the processing gas, the flow rate of the processing gas is 450 sccm, and the coil power is 2000 W. Also, in forming the protective film **92** in the supporting film **5**, mixed gas of C_4F_8 and O_2 is used as the processing gas, the flow rate of the processing gas is 150 sccm, and the coil power is 1500 W. The processing time of the etching process is 5 seconds, and the time for forming the protective film **92** is 3 seconds. The etching process and the formation of the protective film **92** are conducted alternately for 20 minutes in total. With that, the process is finished.

Embodiment of Ultrasonic Examination Device

FIG. **9** is a block diagram showing the embodiment of the ultrasonic examination device according to the invention. As shown in FIG. **9**, the diagnostic device **100** has the above-described ultrasonic probe **10**, and the device main body **300** which is electrically connected with the ultrasonic probe **10** through the cable **210**.

The device main body **300** has a control section (control means) **310**, a drive signal generating section **320**, a detection signal processing section **330**, an image signal processing section **340**, and an image display section (display means) **350**. The signal processing section is constructed of the detection signal processing section **330** and the image signal processing section **340**. The control section **310** is constructed of a microcomputer and the like, for example, and controls the entire device main body **300** such as the drive signal generating section **320** and the image signal processing section **340**. The image display section **350** is constructed of a display device such as a CRT or an LCD, for example.

Next, the operation of the diagnostic device **100** will be explained. In conducting a test, the surface of the acoustic matching section **6** of the ultrasonic probe **10** is applied to a living body as a test target, and the diagnostic device **100** is activated. First, when the control section **310** outputs a transmission order to the drive signal generating section **320**, the drive signal generating section **320** transmits a drive signal for driving each ultrasonic element **8** to the ultrasonic element **8** at a predetermined timing. In this manner, each of the ultrasonic elements **8** is driven at a predetermined timing. Then, ultrasonic waves are transmitted from the ultrasonic transducer **1** of the ultrasonic probe **10**.

The transmitted ultrasonic waves propagate through a living body, and the ultrasonic waves reflected on a predetermined part of the living body are input to the ultrasonic transducer **1** of the ultrasonic probe **10**. Then, a detection signal corresponding to the input ultrasonic waves are output from the ultrasonic transducer **1**. The detection signal is transmitted to the detection signal processing section **330** of the device main body **300** through the cable **210**. The detection signal undergoes predetermined signal processing in the detection signal processing section **330**, and is converted into a digital signal by an A/D converter included in the detection signal processing section **330**. The A/D converter is not shown in the drawing.

The digital signal output from the detection signal processing section **330** is input to the image signal processing section **340**, and is sequentially stored in a primary storing section included in the image signal processing section **340** as areal data in synchronization with a frame timing signal. The primary storing section is not shown in the drawing. The image signal processing section **340** reconstructs two-dimensional or three-dimensional image data based on each areal data, and also conducts image processing such as interpolation, response emphasis processing, or tone processing to the image data. The image data, to which image processing has been conducted, is stored in a secondary storing section included in the image signal processing section **340**. The secondary storing section is not shown in the drawing. The image data, to which image processing has been conducted, is then read out from the secondary storing section of the image signal processing section **340** and is input to the image display section **350**. The image display section **350** displays an image based on the image data. A medical service worker such as a doctor conducts diagnosis or the like by observing an image displayed on the image display section **350**.

The invention is not limited to the ultrasonic transducer, the ultrasonic probe, and the ultrasonic examination device of the invention explained in the above based on the embodiment shown in the drawing. The configuration of each section can be replaced with any configuration that has a similar function. Also, another optional element can be added to the invention.

In the above-described embodiment, the number of the ultrasonic element, that is, the numbers of the parts of the piezoelectric element and the supporting film corresponding to the opening are plural, respectively. However, the invention is not limited to this, and they can be single.

The advantage of the embodiment is to provide an ultrasonic transducer, an ultrasonic probe, and an ultrasonic examination device which have good characteristics of transmission and reception of ultrasonic waves, and can prevent the part of the supporting film corresponding to the opening from being damaged.

This advantage is achieved by the embodiment described below. According to one aspect of the embodiment, an ultrasonic transducer includes a substrate, a supporting film, and a piezoelectric element. The substrate includes an opening. The supporting film is configured on the substrate to cover the opening. The piezoelectric element is configured at a part (an opening-overlapping part) of the supporting film. The part overlaps with the opening in a planar view in a thickness direction of the substrate. A thickness of the part at a center of gravity in the planar view is smaller than a thickness of an outer edge portion of the part. The outer edge portion is closer to the substrate than the center to the substrate.

According to another aspect of the embodiment, an ultrasonic transducer includes a substrate, a support film, and a piezoelectric element. The substrate includes an opening. The supporting film is configured on the substrate to cover the opening. The piezoelectric element is configured at a part of the supporting film. The part overlaps with the opening in a planar view in a thickness direction of the substrate. A surface of the part on an opening side having a curved concave surface.

GENERAL INTERPRETATION OF TERMS

In understanding the scope of the present invention, the term “comprising” and its derivatives, as used herein, are intended to be open ended terms that specify the presence of the stated features, elements, components, groups, integers, and/or steps, but do not exclude the presence of other unstated features, elements, components, groups, integers and/or steps. The foregoing also applies to words having similar meanings such as the terms, “including”, “having” and their derivatives. Also, the terms “part,” “section,” “portion,” “member” or “element” when used in the singular can have the dual meaning of a single part or a plurality of parts. Finally, terms of degree such as "substantially", "about" and "approximately" as used herein mean a reasonable amount of deviation of the modified term such that the end result is not significantly changed. For example, these terms can be construed as including a deviation of at least ±5% of the modified term if this deviation would not negate the meaning of the word it modifies.

While only selected embodiments have been chosen to illustrate the present invention, it will be apparent to those skilled in the art from this disclosure that various changes and modifications can be made herein without departing from the scope of the invention as defined in the appended claims. Furthermore, the foregoing descriptions of the embodiments according to the present invention are provided for illustration only, and not for the purpose of limiting the invention as defined by the appended claims and their equivalents.

What is claimed is:

1. An ultrasonic transducer comprising:

a substrate having an opening;

a supporting film disposed on the substrate to cover the opening; and

a piezoelectric element disposed on the supporting film, the piezoelectric element being disposed on an opening-overlapping part of the supporting film, the opening-overlapping part overlapping the opening in a plan view,

the opening-overlapping part having a portion with thickness that gradually increases from a center portion of the opening-overlapping part toward an outer edge portion of the opening-overlapping part, the center portion being located in an area inside relative to a width of the piezoelectric element in the plan view.

2. The ultrasonic transducer according to claim **1**, wherein

the portion is disposed between the center portion and the outer edge portion, and the portion partially overlaps the piezoelectric element in the plan view.

3. The ultrasonic transducer according to claim **1**, wherein

the supporting film includes a surface facing the opening, and the surface has a curved concave surface.

4. The ultrasonic transducer according to claim **1**, wherein

the opening-overlapping part of the supporting film has a uniform thickness portion a thickness of which is uniform at the outer edge portion.

5. The ultrasonic transducer according to claim **4**, wherein

the uniform thickness portion is arranged along a whole circumference of the opening-overlapping part in the plan view.

6. The ultrasonic transducer according to claim **4**, wherein

the piezoelectric element is arranged on the supporting film such that the piezoelectric element does not overlap the uniform thickness portion.

7. The ultrasonic transducer according to claim **4**, wherein

a thickness of the uniform thickness portion of the supporting film is D**1**,

a thickness of the thinnest portion of the supporting film at the opening-overlapping part is D**2**, and

D**2**/D**1** is within the range of 0.1 to 0.9.

8. The ultrasonic transducer according to claim **1**, further comprising

an acoustic matching section disposed on the piezoelectric element.

9. The ultrasonic transducer according to claim **8**, wherein

an acoustic impedance of the acoustic matching section is equal to an acoustic impedance of a living body.

10. An ultrasonic transducer comprises

a substrate including an opening;

a supporting film disposed on the substrate;

a piezoelectric element disposed on the supporting film, the piezoelectric element being disposed on an area that overlaps the opening in a plan view in a thickness direction of the substrate;

an acoustic matching section disposed on the piezoelectric element; and

a piezoelectric array in which a plurality of piezoelectric elements including the piezoelectric element are arranged,

the acoustic matching section being disposed on the piezoelectric array,

the piezoelectric array including a first piezoelectric element and a second piezoelectric element different from the first piezoelectric element,

the acoustic matching section covering the first piezoelectric element and the second piezoelectric element,

the acoustic matching section having a flat surface,

a thickness of the supporting film at an area that overlaps the piezoelectric element in a plan view of the supporting film being smaller than a thickness of the supporting film at a different area different from the area that overlaps the piezoelectric element.

11. An ultrasonic probe comprising:

a case; and

the ultrasonic transducer according to claim **1**, which is accommodated in the case.

12. An ultrasonic examination device comprising:

an ultrasonic probe including a case, and the ultrasonic transducer according to claim **1**, which is accommodated in the case; and

a device main body including a signal processing section that is configured to conduct a signal processing based on a signal transmitted from the ultrasonic probe.

* * * * *

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摘要(译)

超声换能器包括基板，设置在基板上的支撑膜，以及设置在支撑膜上的压电元件。基板包括开口。压电元件设置在与基板的厚度方向上的平面图中的开口重叠的区域上。在支撑膜的平面图中与压电元件重叠的区域处的支撑膜的厚度小于在与压电元件重叠的区域不同的不同区域处的支撑膜的厚度。