



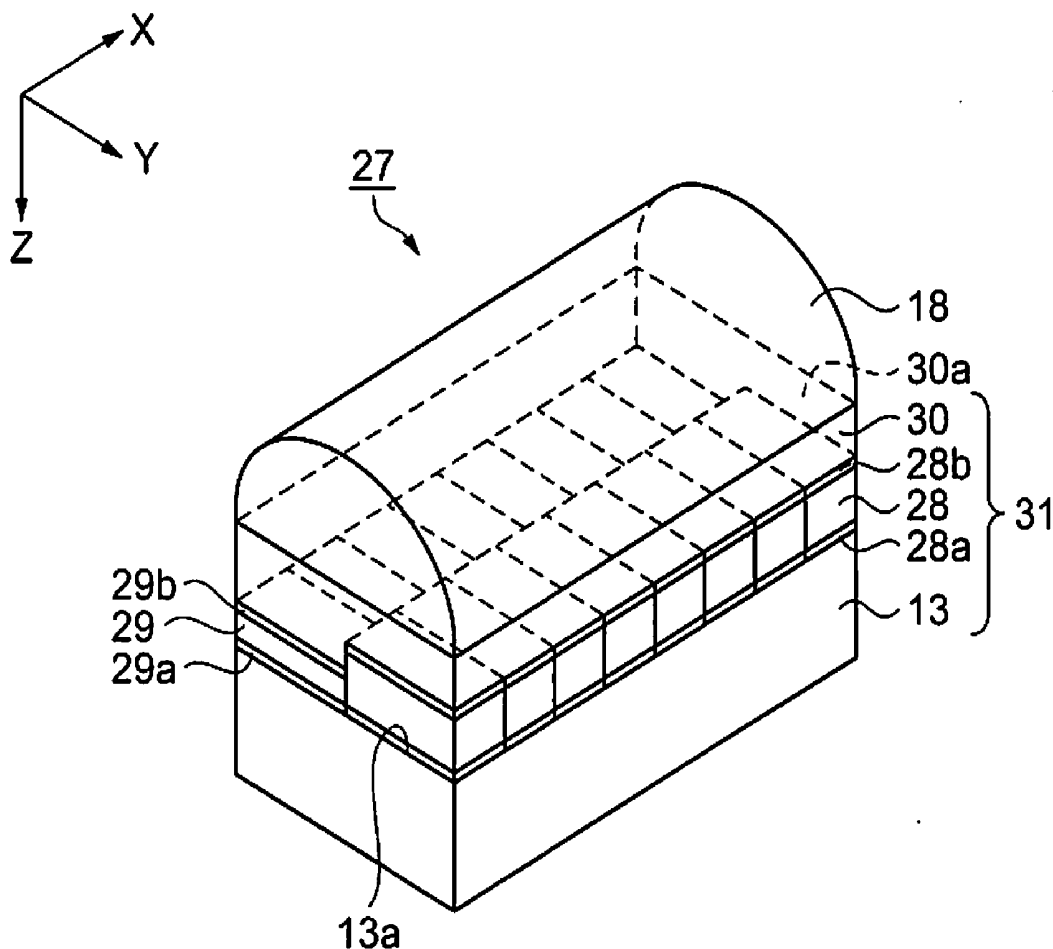
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(19) **United States**(12) **Patent Application Publication**
Kiyose et al.(10) **Pub. No.: US 2015/0105663 A1**(43) **Pub. Date: Apr. 16, 2015**(54) **ULTRASONIC DEVICE, ULTRASONIC
PROBE, ULTRASONIC DIAGNOSTIC
APPARATUS, AND METHOD OF
MANUFACTURING ULTRASONIC DEVICE***A61B 8/08* (2006.01)*B06B 1/06* (2006.01)(52) **U.S. Cl.**CPC *A61B 8/4494* (2013.01); *B06B 1/0622*
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Publication Classification(51) **Int. Cl.***A61B 8/00* (2006.01)*A61B 8/14* (2006.01)**ABSTRACT**

An ultrasonic device includes a substrate, a first piezoelectric body, a second piezoelectric body, and an acoustic matching section. The substrate has a first surface that is a flat surface. The first piezoelectric body is disposed on the first surface of the substrate. The second piezoelectric body is disposed on the first surface of the substrate. The second piezoelectric body has a different thickness from a thickness of the first piezoelectric body as measured from the first surface of the substrate. The acoustic matching section is disposed on the first piezoelectric body and the second piezoelectric body. The acoustic matching section has a first side facing the first piezoelectric body and the second piezoelectric body, and a second side opposite from the first side. A surface of the acoustic matching section on the second side is a flat surface parallel with the first surface of the substrate.



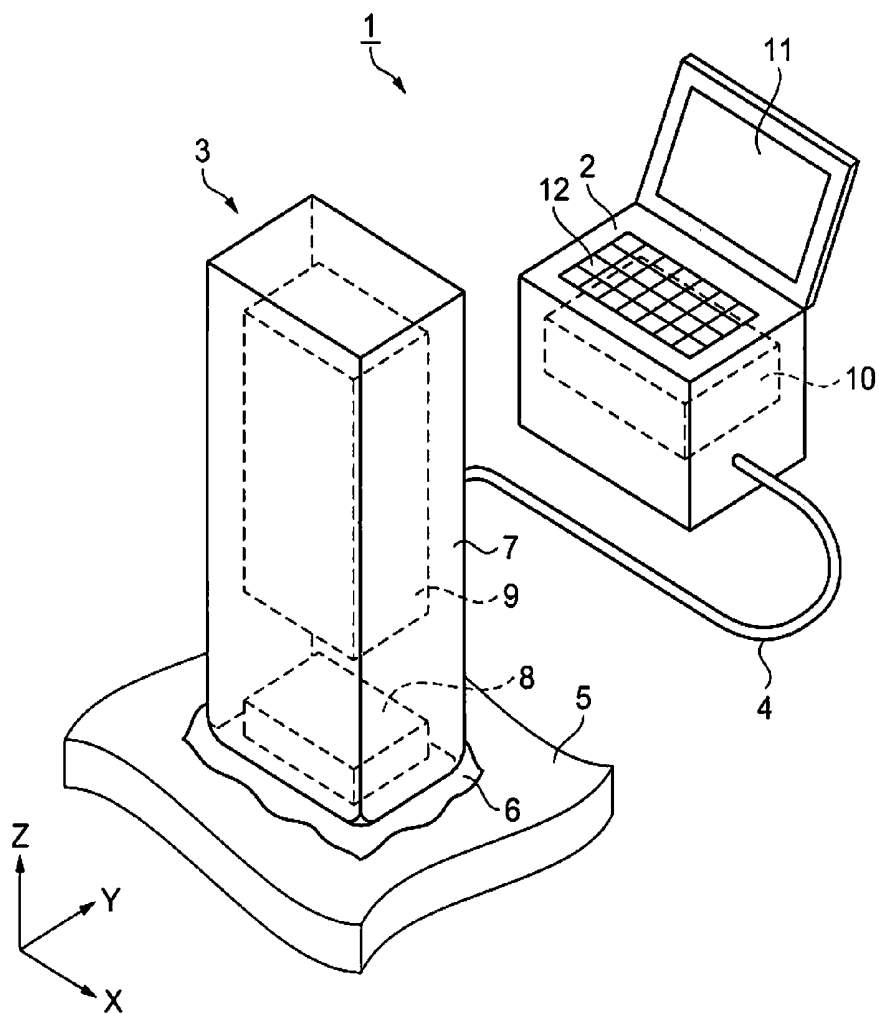


Fig. 1A

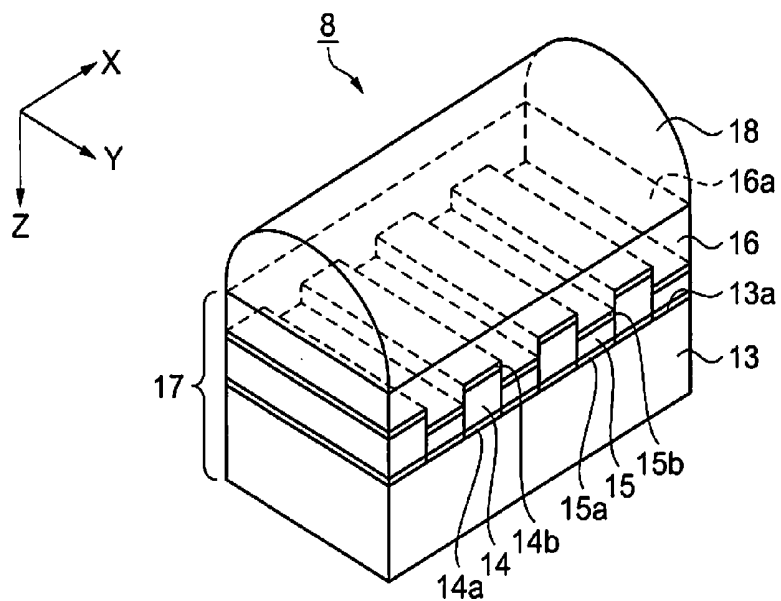


Fig. 1B

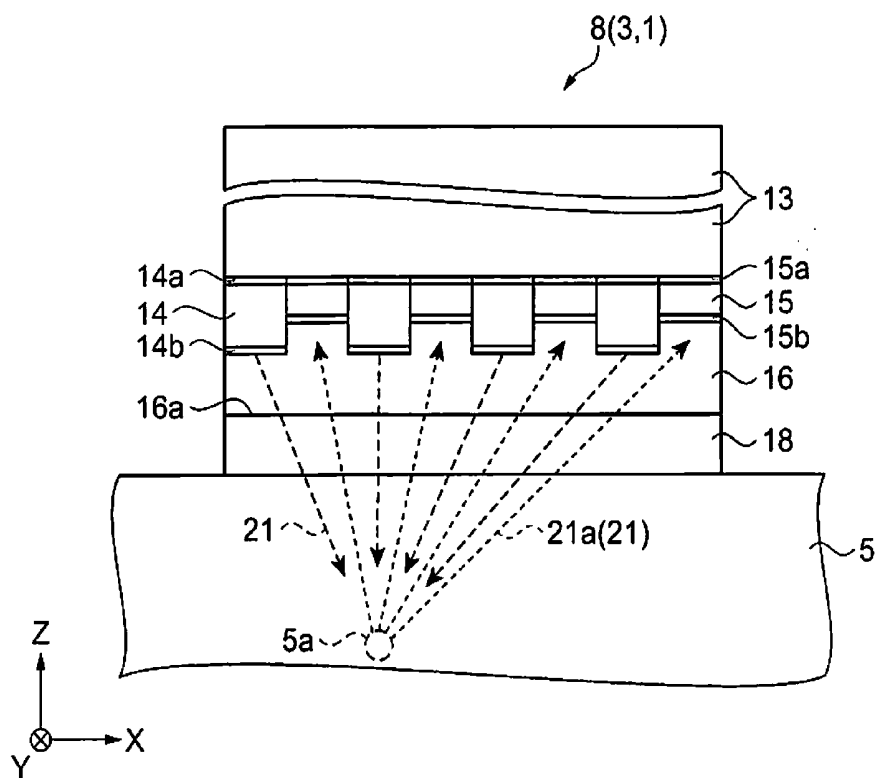


Fig. 2A

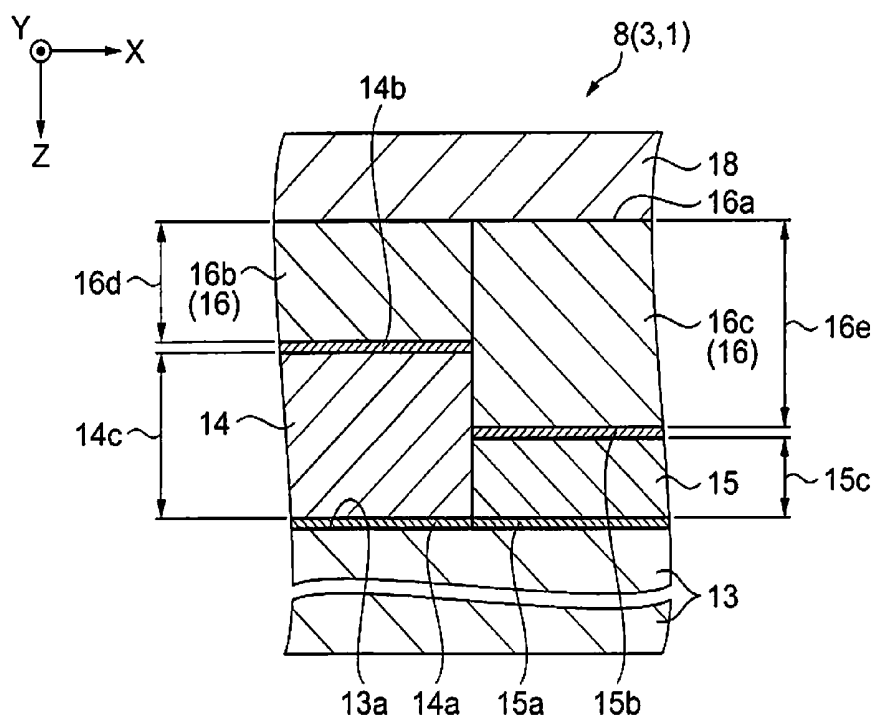


Fig. 2B

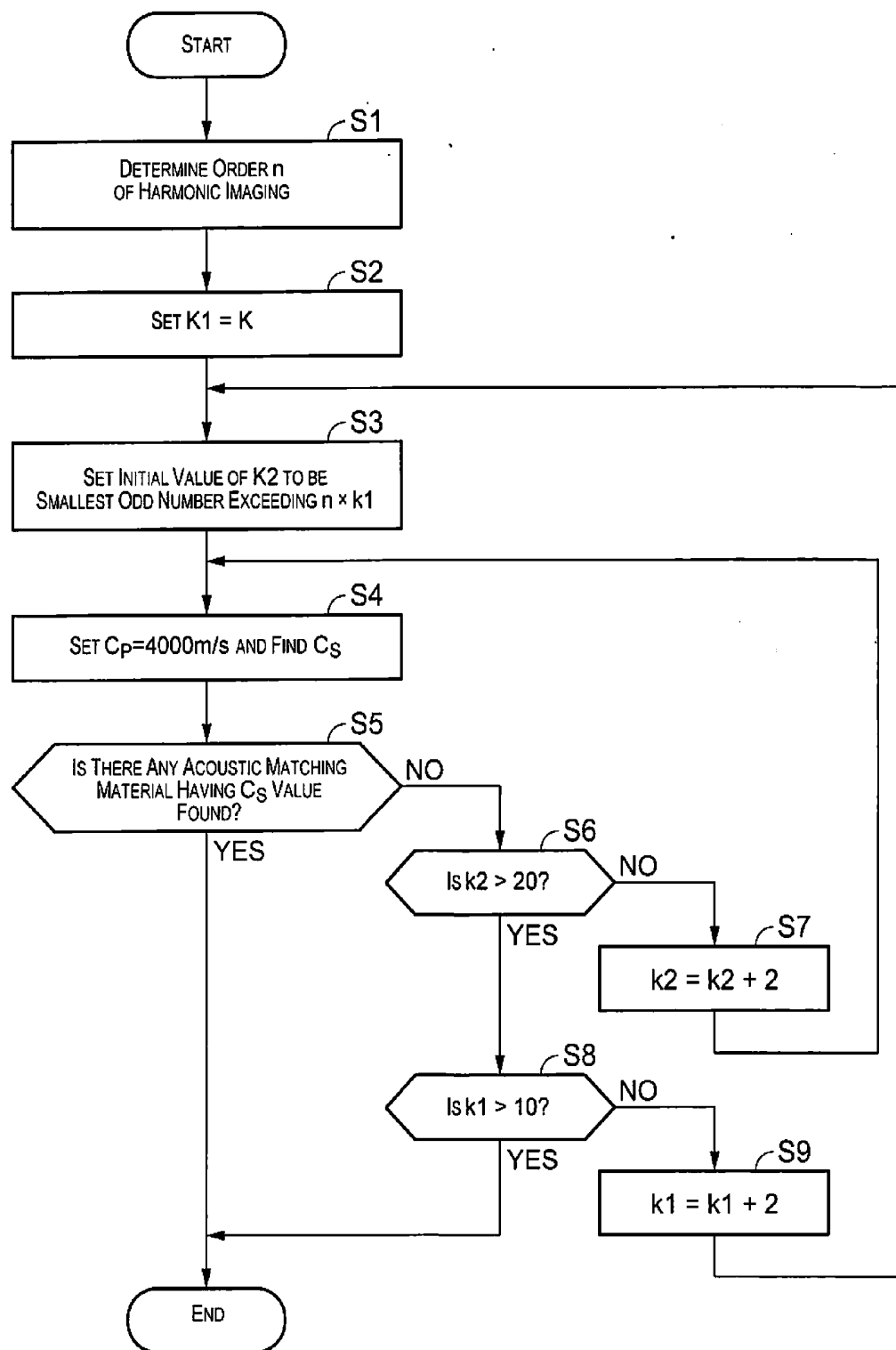


Fig. 3

n = 2

k1	k2	d1	t1	d2	t2	$\frac{C_p}{C_s}$	C_s (m/s) WHEN $C_p=4,000$ (m/s)	APPLICABLE ACOUSTIC MATCHING MATERIALS	SUITABILITY OF ACOUSTIC MATCHING MATERIALS
1	3	$\frac{C_p}{2f_1}$	$\frac{C_s}{4f_1}$	$\frac{C_p}{4f_1}$	$\frac{3C_s}{8f_1}$	0.5	8,000	SPECIAL METALS	×
	5				$\frac{5C_s}{8f_1}$	1.5	2,667	POLYMER MATERIALS	○
	7				$\frac{7C_s}{8f_1}$	2.5	1,600	NATURAL RUBBERS	⊙
	9				$\frac{9C_s}{8f_1}$	3.5	1,143	SILICON	⊙
	⋮				⋮	⋮	⋮	⋮	⋮
3	7	$\frac{C_p}{2f_1}$	$\frac{3C_s}{4f_1}$	$\frac{C_p}{4f_1}$	$\frac{7C_s}{8f_1}$	0.5	8,000	SPECIAL METALS	×
	9				$\frac{9C_s}{8f_1}$	1.5	2,667	POLYMER MATERIALS	○
	⋮				⋮	⋮	⋮	⋮	⋮

Fig. 4

n = 3

k1	k2	d1	t1	d2	t2	$\frac{C_p}{C_s}$	C_s (m/s) WHEN $C_p=4,000$ (m/s)	APPLICABLE ACOUSTIC MATCHING MATERIALS	SUITABILITY OF ACOUSTIC MATCHING MATERIALS
1	5	$\frac{C_p}{2f_1}$	$\frac{C_s}{4f_1}$	$\frac{C_p}{6f_1}$	$\frac{5C_s}{12f_1}$	0.5	8,000	SPECIAL METALS	×
	7				$\frac{7C_s}{12f_1}$	1.0	4,000	CERAMICS	△
	9				$\frac{9C_s}{12f_1}$	1.5	2,667	POLYMER MATERIALS	○
	11				$\frac{11C_s}{12f_1}$	2.0	2,000	POLYETHYLENE	◎
	⋮				⋮	⋮	⋮	⋮	⋮
3	11	$\frac{C_p}{2f_1}$	$\frac{3C_s}{4f_1}$	$\frac{C_p}{6f_1}$	$\frac{11C_s}{12f_1}$	0.5	8,000	SPECIAL METALS	×
	13				$\frac{13C_s}{12f_1}$	1.0	4,000	CERAMICS	△
	15				$\frac{15C_s}{12f_1}$	1.5	2,667	POLYMER MATERIALS	○
	⋮				⋮	⋮	⋮	⋮	⋮

Fig. 5

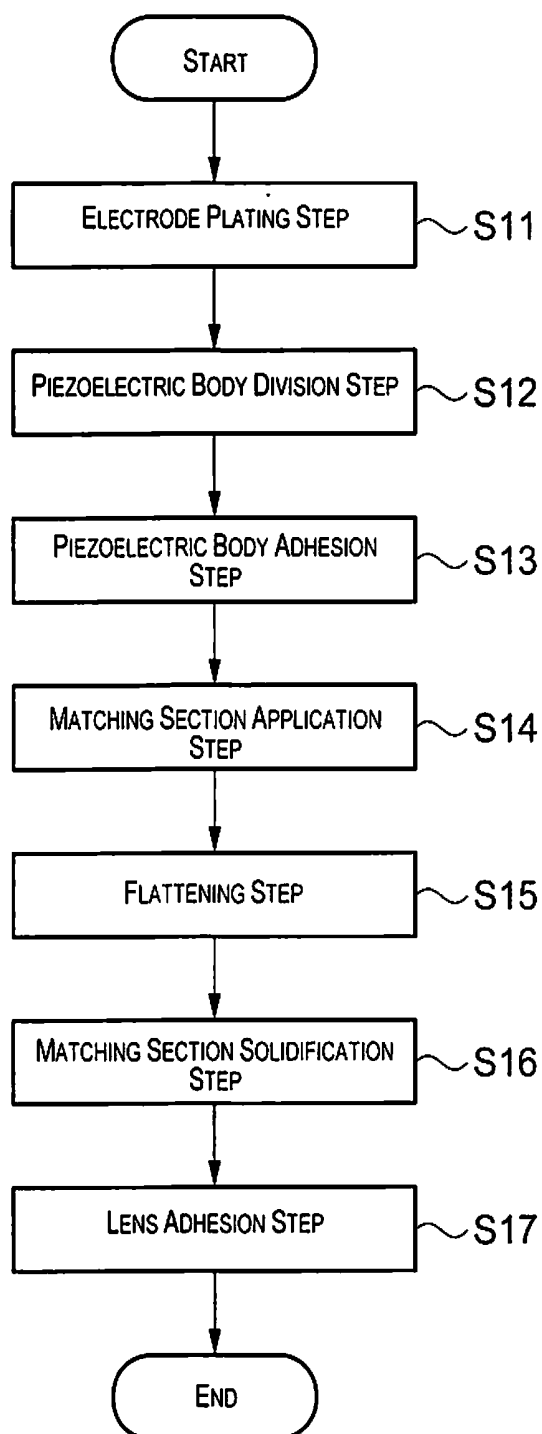
**Fig. 6**

Fig. 7A

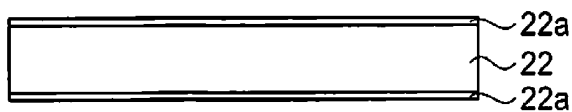


Fig. 7B

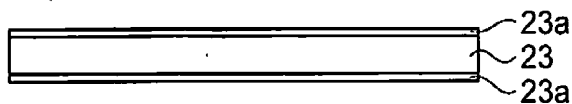


Fig. 7C

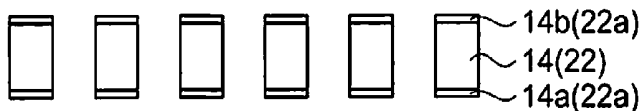


Fig. 7D

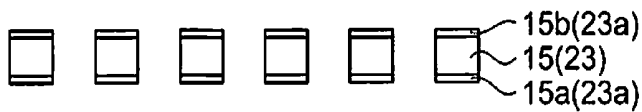


Fig. 7E

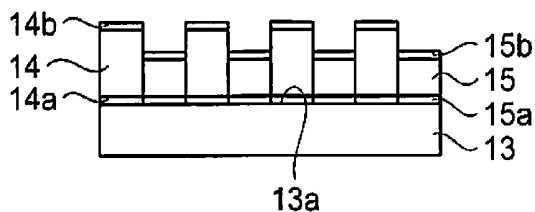


Fig. 7F

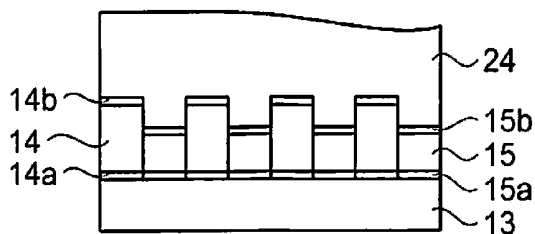
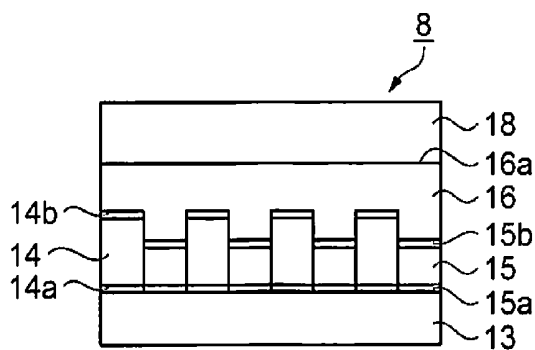


Fig. 7G



Fig. 7H



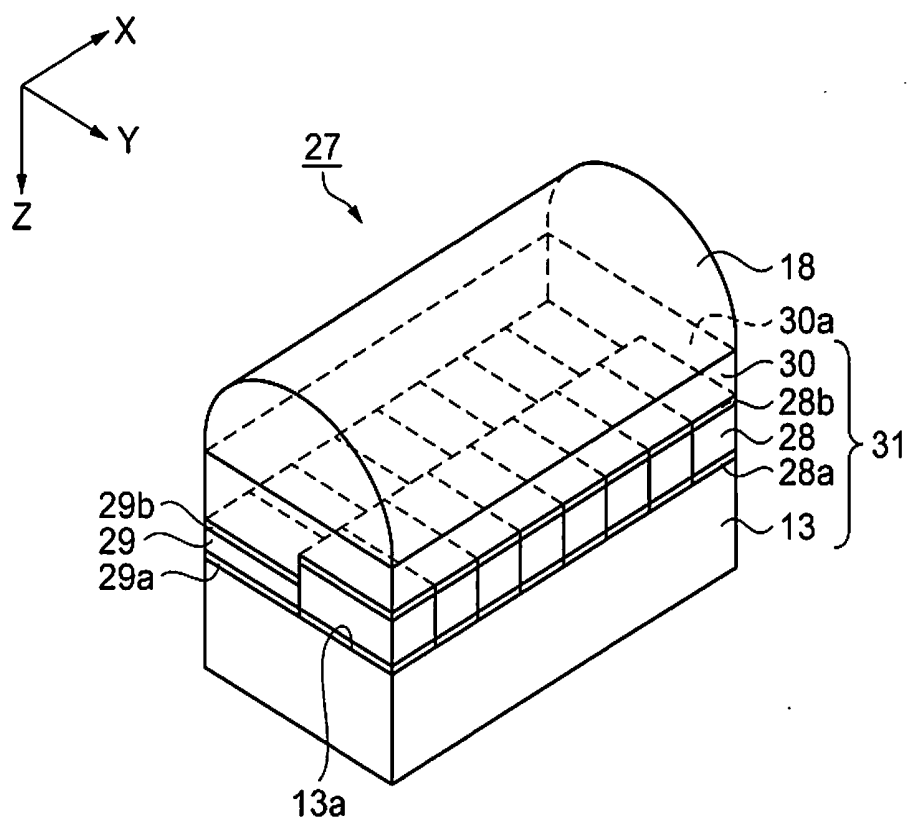


Fig. 8

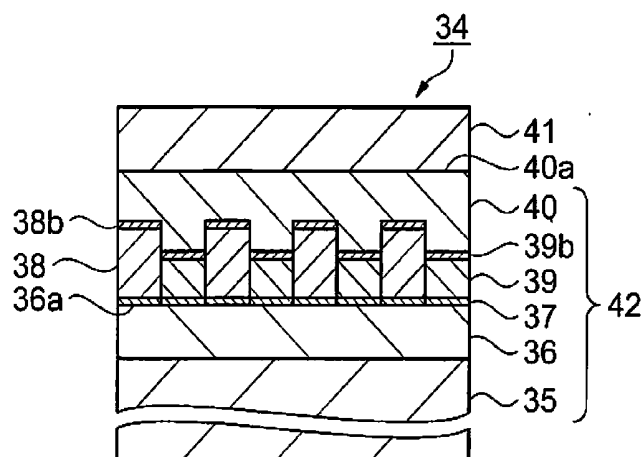


Fig. 9A

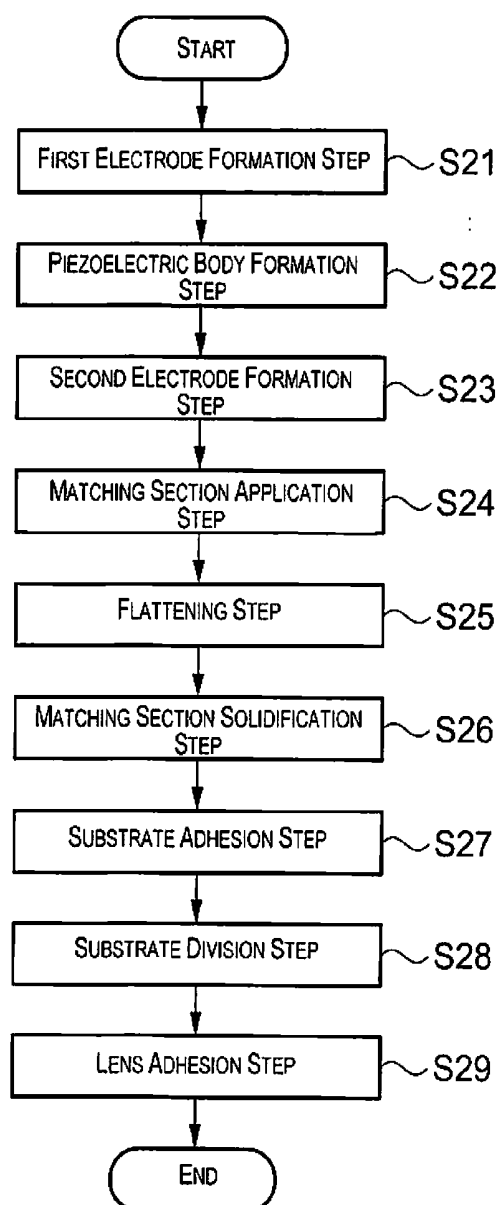


Fig. 9B

Fig. 10A

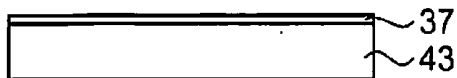


Fig. 10B

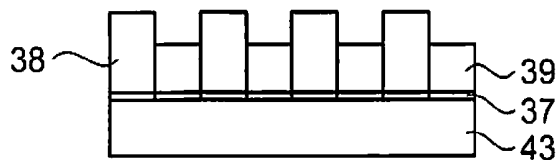


Fig. 10C

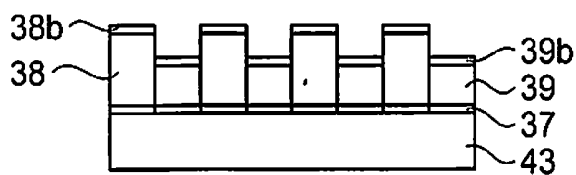


Fig. 10D

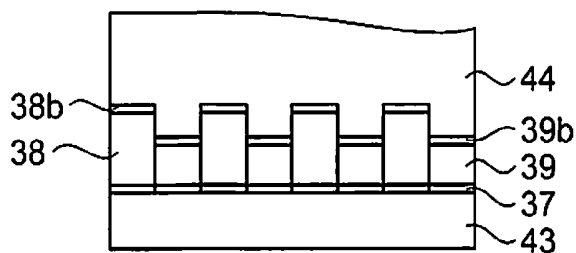


Fig. 10E

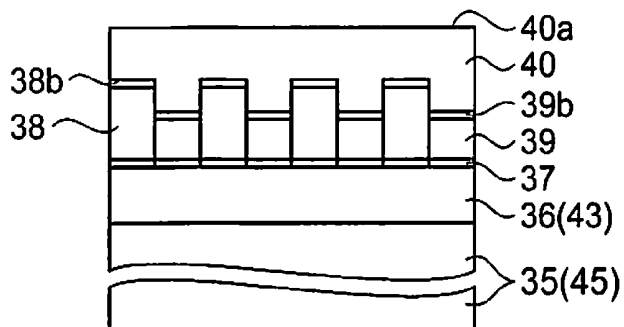
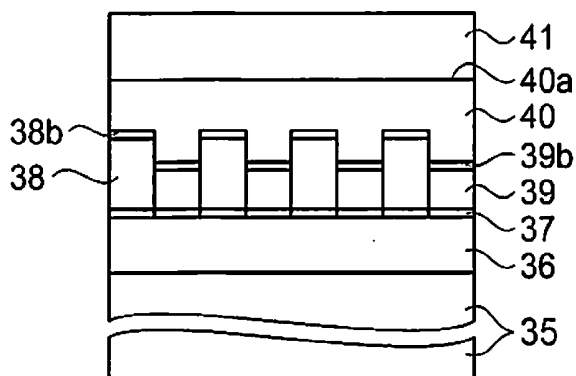


Fig. 10F



**ULTRASONIC DEVICE, ULTRASONIC
PROBE, ULTRASONIC DIAGNOSTIC
APPARATUS, AND METHOD OF
MANUFACTURING ULTRASONIC DEVICE**

CROSS-REFERENCE TO RELATED
APPLICATIONS

[0001] This application claims priority to Japanese Patent Application No. 2013-213463 filed on Oct. 11, 2013. The entire disclosure of Japanese Patent Application No. 2013-213463 is hereby incorporated herein by reference.

BACKGROUND

[0002] 1. Technical Field

[0003] The present invention relates to an ultrasonic device, an ultrasonic probe, an ultrasonic diagnostic apparatus, and a method of manufacturing an ultrasonic device.

[0004] 2. Related Art

[0005] Ultrasonic devices for transmitting and receiving ultrasonic waves have been widely used in ultrasonic diagnostic apparatuses and the like. Then, generally used in an ultrasonic device is a vibrator where electrodes are formed at both ends of a piezoelectric body of, inter alia, a piezoelectric ceramic, of which lead (Pb) zirconium titanate (PZT) is representative. Japanese Laid-Open Patent Publication No. 1-12-49640 discloses such an ultrasonic device. According thereto, ultrasonic devices have different thicknesses of PZT installed on a substrate, where there are stepped differences. Vibrators of low resonant frequency are installed on the lower stages, and vibrators of high resonant frequency are installed on the upper stages.

[0006] Then, an acoustic matching layer is arranged so as to overlap the respective vibrators. Where the opposite side of the vibrators is understood to be the front surface, the acoustic matching layer has a front surface that is formed so as to be flat. Having a flat front surface makes it possible to easily make contact with a test subject. The thickness of the acoustic matching layer and the thickness of the vibrators are set so as to correspond to the resonant frequency. The difference in length found by adding both the thickness of the acoustic matching layer and the thickness of the vibrators will be the height of the stepped differences of the substrate. As such, providing the stepped differences to the substrates makes it possible to properly set both the lengths of the vibrators and the length of the acoustic matching layer even though the front surface is a flat one.

SUMMARY

[0007] In Japanese Laid-Open Patent Publication No. H2-49640, the stepped differences of the substrate correspond to elements of the vibrators, and therefore the number of stepped differences is increased by an amount commensurate with any increase in the number of vibrators. As such, the substrate is more difficult to manufacture in an ultrasonic device of a structure where many vibrators are arranged on the substrate. Therefore, there has been a desire for an ultrasonic device of a structure that is easy to manufacture even when there are many pluralities of vibrators having different resonant frequencies arranged thereon.

[0008] The present invention has been made in order to solve this problem, and can be implemented as the following aspects.

[0009] An ultrasonic device according to one aspect includes a substrate, a first piezoelectric body, a second piezoelectric body, and an acoustic matching section. The substrate has a first surface that is a flat surface. The first piezoelectric body is disposed on the first surface of the substrate. The second piezoelectric body is disposed on the first surface of the substrate. The second piezoelectric body has a different thickness from a thickness of the first piezoelectric body as measured from the first surface of the substrate. The acoustic matching section is disposed on the first piezoelectric body and the second piezoelectric body. The acoustic matching section has a first side facing the first piezoelectric body and the second piezoelectric body, and a second side opposite from the first side. A surface of the acoustic matching section on the second side is a flat surface parallel with the first surface of the substrate.

[0010] According to this aspect, the ultrasonic device is provided with the first piezoelectric body and the second piezoelectric body on the substrate. Applying an alternating current voltage causes the first piezoelectric body to emit ultrasonic waves. The acoustic matching section is provided onto the first piezoelectric body and the second piezoelectric body. The emitted waves pass through the acoustic matching section and are emitted into a test subject. Reflected in the test subject, the ultrasonic waves pass through the acoustic matching section and are incident on the second piezoelectric body. With the acoustic matching section, the acoustic impedance is adjusted and therefore the ultrasonic waves can efficiently travel through between the first piezoelectric body, the test subject, and the second piezoelectric body.

[0011] The ultrasonic waves are incident on the second piezoelectric body, which then output a signal of an alternating current voltage. Because the first piezoelectric body and the second piezoelectric body have different thicknesses, the resonant frequencies of each of the piezoelectric bodies are different frequencies. As such, the ultrasonic device emits the ultrasonic waves toward the test subject from the first piezoelectric body, and the second piezoelectric body is able to detect ultrasonic waves of a different frequency out of the ultrasonic waves that are reflected in the test subject. Then, the first surface where the first piezoelectric body and the second piezoelectric body are installed in the substrate is a flat surface. The surface on the second side of the acoustic matching section opposite to the first piezoelectric body and the second piezoelectric body is also a flat surface. As such, the substrate has a shape that facilitates processing compared to when unevenness is provided to the first surface. The acoustic matching section has a shape that facilitates processing compared to when unevenness is provided to the surface on the second side. As a result, the ultrasonic device can be manufactured at high productivity.

[0012] In the ultrasonic device according to the aspect, the following formulae (1) to (7) are preferably satisfied, where C_p is a speed of sound in the first piezoelectric body and the second piezoelectric body, C_s is a speed of sound in the acoustic matching section, f_1 is a resonant frequency of the first piezoelectric body, f_2 is a resonant frequency of the second piezoelectric body, d_1 is the thickness of the first piezoelectric body, d_2 is the thickness of the second piezoelectric body, t_1 is a thickness of the acoustic matching section as measured from a surface of the first piezoelectric body, t_2 is a thickness of the acoustic matching section as measured from a surface of the second piezoelectric body, n is an integer, and k_1 and k_2 are odd numbers.

$$f_2 = n \times f_1 \quad \text{formula (1)}$$

$$d_1 = C_p / (2 \times f_1) \quad \text{formula (2)}$$

$$d_2 = C_p / (2 \times f_2) \quad \text{formula (3)}$$

$$t_1 = k_1 \times C_s / (4 \times f_1) \quad \text{formula (4)}$$

$$t_2 = k_2 \times C_s / (4 \times f_2) \quad \text{formula (5)}$$

$$d_1 + t_1 = d_2 + t_2 \quad \text{formula (6)}$$

$$C_s = 2 \times (n-1) \times C_p / (k_2 - n \times k_1) \quad \text{formula (7)}$$

[0013] According to this aspect, as illustrated in the formula (1), the resonant frequency of the second piezoelectric body will be an integer multiple of the resonant frequency of the first piezoelectric body. As such, the first piezoelectric body outputs ultrasonic waves, and the second piezoelectric body can detect an n-th order of higher frequency of ultrasonic waves reflected in the test subject. Having the thickness d_1 of the first piezoelectric body be as illustrated in the formula (2) makes it possible to have the resonant frequency of the first piezoelectric body be the resonant frequency f_1 . Likewise, having the thickness d_2 of the second piezoelectric body be as illustrated in the formula (3) makes it possible to have the resonant frequency of the second piezoelectric body be the resonant frequency f_2 .

[0014] When the wavelength and frequency of the ultrasonic waves traveling through the acoustic matching section are λ and f , respectively, then there is a relationship $\lambda = C_s / f$. As such, the formula (4) illustrates $t_1 = k_1 \times \lambda / 4$, and the formula (5) illustrates $t_2 = k_2 \times \lambda / 4$. That is to say, the thickness of the acoustic matching section is an odd multiple of $\lambda / 4$. Because being an odd multiple of $\lambda / 4$ is a wavelength matching condition, any incidence where the ultrasonic waves traveling through the acoustic matching section would cancel each other out with the ultrasonic waves reflected in the interface of the acoustic matching section is curbed. As such, the acoustic matching section can allow the ultrasonic waves to travel through efficiently.

[0015] As illustrated by the formula (6), the thickness obtained by adding the thickness of the first piezoelectric body and the thickness of the acoustic matching section that is on the first piezoelectric body is made to be the same thickness as the thickness obtained by adding the thickness of the second piezoelectric body and the thickness of the acoustic matching section thickness that is on the second piezoelectric body. This makes it possible to flatten the first surface, which is where the first piezoelectric body and the second piezoelectric body are installed in the substrate, and also to flatten the surface on the second side of the acoustic matching section opposite to the first piezoelectric body and the second piezoelectric body in the acoustic matching section. Then, the formula (7) is derived from the formulae (1) to (6). C_s is computed by setting n , k_1 , k_2 , and C_p as illustrated by the formula (7). Then, a material with which the speed of sound corresponds to the computed C_s is selected for the material of the acoustic matching section. As such, an ultrasonic device with which the ultrasonic waves efficiently travel through the acoustic matching section can be manufactured at high productivity.

[0016] In the ultrasonic device as in the above-described aspect, the acoustic matching section is preferably made of natural rubber.

[0017] According to this aspect, the material of the acoustic matching section is natural rubber. In the formula (7) of the application example 2, C_s can be made to be 1600 m/s when $n=2$, $k_1=1$, $k_2=7$, and $C_p=4000$ m/s. Then, the natural rubber fits for when $C_s=1600$ m/s. Natural rubbers have excellent workability. As such, using a natural rubber for the material of the acoustic matching section makes it possible to manufacture at high productivity an ultrasonic device with which the ultrasonic waves travel efficiently through the acoustic matching section.

[0018] In the ultrasonic device as in the above-described aspect, the acoustic matching section is preferably made of silicone resin.

[0019] According to this aspect, the material of the acoustic matching section is silicone resin. In the formula (7) of the application example 2, C_s can be made to be 1143 m/s when $n=2$, $k_1=1$, $k_2=9$, and $C_p=4000$ m/s. Then, the silicone resin fits for when $C_s=1143$ m/s. Silicone resins have excellent workability. As such, using a silicone resin for the material of the acoustic matching section makes it possible to manufacture at high productivity an ultrasonic device with which the ultrasonic waves travel efficiently through the acoustic matching section.

[0020] In the ultrasonic device as in the above-described aspect, the acoustic matching section is preferably made of polyethylene resin.

[0021] According to this aspect, the material of the acoustic matching section is polyethylene resin. In the formula (7) of the application example 2, C_s can be made to be 2000 m/s when $n=3$, $k_1=1$, $k_2=11$, and $C_p=4000$ m/s. Then, the polyethylene resin fits for when $C_s=2000$ m/s. Polyethylene resins have excellent workability. As such, using a polyethylene resin for the material of the acoustic matching section makes it possible to manufacture at high productivity an ultrasonic device with which the ultrasonic waves travel efficiently through the acoustic matching section.

[0022] A method of manufacturing an ultrasonic device according to another aspect includes: forming a first piezoelectric body and a second piezoelectric body on a flat first surface of a substrate; and forming an acoustic matching section having a first side facing the first piezoelectric body and the second piezoelectric body, and a second side opposite from the first side, so that a surface of the acoustic matching section on the second side is a flat surface parallel with the first surface of the substrate.

[0023] According to the present application example, the first piezoelectric body and the second piezoelectric body are formed on the substrate. The first surface of the substrate, onto which the first piezoelectric body and the second piezoelectric body are provided, is flat and can be easily processed. The acoustic matching section is formed on the first piezoelectric body and the second piezoelectric body. The surface on the second side of the acoustic matching section opposite to the first piezoelectric body and the second piezoelectric body is flat. As such, the first surface of the substrate and the surface on the second side of the acoustic matching section can both be produced at high productivity.

[0024] An ultrasonic probe according to another aspect includes an ultrasonic device, and a drive section configured and arranged to drive the ultrasonic device. The ultrasonic device includes a substrate, a first piezoelectric body, a second piezoelectric body, and an acoustic matching section. The substrate has a first surface that is a flat surface. The first piezoelectric body is disposed on the first surface of the

substrate. The second piezoelectric body is disposed on the first surface of the substrate. The acoustic matching section is disposed on the first piezoelectric body and the second piezoelectric body. The acoustic matching section has a first side facing the first piezoelectric body and the second piezoelectric body, and a second side opposite from the first side. A surface of the acoustic matching section on the second side is a flat surface parallel with the first surface of the substrate.

[0025] According to this aspect, the ultrasonic probe is provided with the ultrasonic device and the drive section. The drive section drives the ultrasonic device. In the ultrasonic device, the first surface onto which the first piezoelectric body and the second piezoelectric body are provided in the substrate is a flat surface. The surface on the second side of the acoustic matching section opposite to the first piezoelectric body and the second piezoelectric body is also a flat surface. As such, the substrate has a shape that facilitates processing compared to when unevenness is provided to the first surface. The acoustic matching section has a shape that facilitates processing compared to when unevenness is provided to the surface on the second side. As a result, an ultrasonic probe can be made into an ultrasonic probe provided with an ultrasonic device that can be manufactured at high productivity.

[0026] An ultrasonic diagnostic apparatus according to another aspect includes an ultrasonic device, a drive section, a reflection distribution computation section, and a display section. The ultrasonic device is configured and arranged to emit ultrasonic waves at a test subject and to detect ultrasonic waves that are reflected in the test subject. The drive section is configured and arranged to drive the ultrasonic device. The reflection distribution computation section is configured to compute distribution of reflectance of ultrasonic waves in the test subject from the ultrasonic waves detected by the ultrasonic device. The display section is configured and arranged to display an image based on the distribution of reflectance of ultrasonic waves in the test subject as computed by the reflection distribution computation section. The ultrasonic device includes a substrate, a first piezoelectric body, a second piezoelectric body, and an acoustic matching section. The substrate has a first surface that is a flat surface. The first piezoelectric body is disposed on the first surface of the substrate. The second piezoelectric body is disposed on the first surface of the substrate. The acoustic matching section is disposed on the first piezoelectric body and the second piezoelectric body. The acoustic matching section has a first side facing the first piezoelectric body and the second piezoelectric body, and a second side opposite from the first side. A surface of the acoustic matching section on the second side is a flat surface parallel with the first surface of the substrate.

[0027] According to this aspect, the ultrasonic diagnostic apparatus is provided with the ultrasonic device, the drive section, the reflection distribution computation section, and the display section. The drive section drives the ultrasonic device. The ultrasonic device emits ultrasonic waves at the test subject, and detects ultrasonic waves that are reflected in the test subject. The reflection distribution computation section computes the distribution of reflectance of ultrasonic waves in the test subject from the ultrasonic waves that are detected by the ultrasonic device. The display section displays the distribution of reflectance of ultrasonic waves in the test subject as computed by the reflection distribution computation section. An operator can know the distribution of reflectance of ultrasonic waves in the interior of the test subject by looking at the display section.

[0028] In the ultrasonic device, the first surface onto which the first piezoelectric body and the second piezoelectric body are provided in the substrate is a flat surface. The surface on the second side of the acoustic matching section opposite to the first piezoelectric body and the second piezoelectric body is also flat. As such, the substrate has a shape that facilitates processing compared to when unevenness is provided to the first surface. The acoustic matching section has a shape that facilitates processing compared to when unevenness is provided to the surface on the second side. As a result, an ultrasonic diagnostic apparatus can be made into an ultrasonic diagnostic apparatus provided with an ultrasonic device that can be manufactured at high productivity.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] Referring now to the attached drawings which form a part of this original disclosure:

[0030] FIG. 1A is a schematic perspective view illustrating a structure of an ultrasonic image apparatus and FIG. 1B is a schematic perspective view illustrating a structure of an ultrasonic sensor according to a first embodiment;

[0031] FIG. 2A is a schematic diagram for describing emission and detection of ultrasonic waves in an ultrasonic sensor, and FIG. 2B is a schematic diagram for describing the relationship between the dimensions of an acoustic matching section and a piezoelectric body;

[0032] FIG. 3 is a flowchart for describing the procedure for selecting the material of an acoustic matching section;

[0033] FIG. 4 is a drawing illustrating the result of material selection for when harmonic imaging has an order of $n=2$;

[0034] FIG. 5 is a drawing illustrating the result of material selection for when harmonic imaging has an order of $n=3$;

[0035] FIG. 6 is a flowchart illustrating a method of manufacturing an ultrasonic sensor;

[0036] FIGS. 7A to 7H are schematic diagrams for describing a method of manufacturing an ultrasonic sensor;

[0037] FIG. 8 is a schematic perspective view illustrating a structure of an ultrasonic sensor as in a second embodiment;

[0038] FIG. 9A is a schematic lateral cross-sectional view illustrating a structure of an ultrasonic sensor and FIG. 9B is a flowchart illustrating a method of manufacturing an ultrasonic sensor according to a third embodiment; and

[0039] FIGS. 10A to 109F are schematic diagrams for describing a method of manufacturing an ultrasonic sensor.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0040] The present embodiment describes an example of an ultrasonic device having a characteristic structure, as well as an ultrasonic probe and ultrasonic image apparatus provided with this ultrasonic device. Embodiments shall be described below, with reference to the accompanying drawings. Each of the members in each of the drawings is given a size large enough to be recognizable on each of the drawings, and therefore every member is depicted with a different dimensional scale.

First Embodiment

[0041] An ultrasonic image apparatus as in a first embodiment shall now be described with reference to FIGS. 1 to 7. FIG. 1A is a schematic perspective view illustrating the structure of the ultrasonic image apparatus. As illustrated in FIG. 1A, an ultrasonic image apparatus 1 is provided with an

image processing apparatus 2 and an ultrasonic probe 3. The image processing apparatus 2 and the ultrasonic probe 3 are connected by a cable 4. The ultrasonic probe 3 is used by being pressed against a test subject 5. The surface of the test subject 5 is coated with a liquid body 6, and the liquid body 6 is interposed between the ultrasonic probe 3 and the test subject 5. The liquid body 6 is endowed with the function of conducting and not reflecting ultrasonic waves emitted by the ultrasonic probe 3.

[0042] The ultrasonic probe 3 is provided with an exterior covering section 7. The shape of the exterior covering section 7 is a bottomed square tube. An ultrasonic sensor 8 is installed on the exterior covering section 7, on a side facing the test subject 5, and the ultrasonic waves are emitted toward the test subject 5 from the ultrasonic sensor 8. The ultrasonic waves are reflected in the interior of the test subject 5. The ultrasonic sensor 8 detects the reflected waves reflected in the interior of the test subject 5. The interior of the exterior covering section 7 houses a sensor drive section 9 serving as a drive section for driving the ultrasonic sensor 8.

[0043] The image processing apparatus 2 is provided with an image computation section 10 serving as a reflection distribution computation section, an image display section 11 serving as a display section, and an input section 12. The image computation section 10 uses a reflected wave signal outputted by the ultrasonic probe 3, to compute the distribution of reflectance in a cross-section of the test subject 5. Then, a cross-sectional image is computed from the result of computation of the distribution of reflectance, and outputted to the image display section 11. The image display section 11 receives the input of the result of computation outputted by the image computation section 10, and displays the cross-sectional image of the test subject 5. The cross-sectional image displays the distribution of reflectance. The input section 12 is a site where command content is inputted to the ultrasonic image apparatus 1 by an operator.

[0044] The longitudinal direction of the ultrasonic probe 3 is understood here to be the Z-direction. For greater detail, the direction in which the ultrasonic probe 3 faces the test subject 5 is understood to be the -Z-direction. The two orthogonal directions on the plane where the ultrasonic probe 3 and the test subject 5 are in contact are understood to be the X-direction and the Y-direction. The X-direction, the Y-direction, and the Z-direction are each respectively orthogonal directions.

[0045] FIG. 1B is a schematic perspective view illustrating a structure of an ultrasonic sensor. As illustrated in FIG. 1B, the ultrasonic sensor 8 is provided with a rectangular substrate 13. The material of the substrate 13 is not particularly limited, provided that the material has a high acoustic attenuation. This material is referred to as a backing material. The substrate 13 is formed by, for example, mixing a powder of metal, ferrite, ceramic, or the like into an elastic member made of an epoxy resin, rubber, or the like.

[0046] In the substrate 13, the surface facing the -Z-direction is understood to be a first surface 13a. The first surface 13a is a flat surface. First piezoelectric bodies 14 and second piezoelectric bodies 15 are arranged alternately side by side on the first surface 13a. The shape of the first piezoelectric bodies 14 is a prism, and first electrodes 14a are installed on a surface of the first piezoelectric bodies 14 facing the substrate 13 side. Second electrodes 14b are installed on surfaces of the opposite side to the first electrodes 14a in the first piezoelectric bodies 14.

[0047] The shape of the second piezoelectric bodies 15 is a prism, and the length of the second piezoelectric bodies 15 in the Y-direction is the same as the length of the first piezoelectric bodies 14. The length of the X-direction width of the second piezoelectric bodies 15 is also the same as the length of the first piezoelectric bodies 14. The length of the Z-direction thickness of the second piezoelectric bodies 15 is shorter than the length of the first piezoelectric bodies 14. First electrodes 15a are installed on a surface of the second piezoelectric bodies 15 facing the substrate 13 side. Second electrodes 15b are installed on a surface of the opposite side to the first electrodes 15a in the second piezoelectric bodies 15.

[0048] For the sake of simplifying the drawings, the depicted first piezoelectric bodies 14 and second piezoelectric bodies 15 are arranged each in increments of four. The numbers of first piezoelectric bodies 14 and second piezoelectric bodies 15 are not particularly limited. When the numbers are greater, the examination range can be widened by a commensurate amount. Alternatively, the resolution can be increased. In the present embodiment, for example, there are 256 of the first piezoelectric bodies 14 and the second piezoelectric bodies 15, each.

[0049] The materials of the first piezoelectric bodies 14 and second piezoelectric bodies 15 are not particularly limited, provided that the material be one where an alternative current voltage is applied and ultrasonic waves are emitted. For the materials of the first piezoelectric bodies 14 and the second piezoelectric bodies 15, it would be possible to use piezoelectric elements such as lead (Pb) zirconium titanate (PZT) elements or polyvinylidene fluoride (PDVF) elements. In the present embodiment, PZT elements, which are one kind of piezoelectric element, are used. The first piezoelectric bodies 14 and the second piezoelectric bodies 15 are also called acoustic transducers.

[0050] When an alternating current voltage is applied between the first electrodes 14a and the second electrodes 14b, then the first piezoelectric bodies 14 emit ultrasonic waves. The first piezoelectric bodies 14 function as elements for emitting ultrasonic waves. The second piezoelectric bodies 15 receive incident ultrasonic waves and generate an alternating current voltage between the first electrodes 15a and the second electrodes 15b. The second piezoelectric bodies 15 function as elements for detecting the ultrasonic waves. Thicker piezoelectric bodies can emit ultrasonic waves of lower frequency and detect ultrasonic waves of lower frequency than thinner piezoelectric bodies. The second piezoelectric bodies 15 are set so as to be thinner than the first piezoelectric bodies 14. This results in the second piezoelectric bodies 15 detecting ultrasonic waves of a frequency higher than the ultrasonic waves emitted by the first piezoelectric bodies 14.

[0051] The surfaces of the first electrodes 14a and first electrodes 15a that face the substrate 13 are flat. The first electrodes 14a are fixed by adhesion to the first surface 13a, and the first electrodes 15a are also fixed by adhesion to the first surface 13a.

[0052] An acoustic matching section 16 is installed on the -Z-direction side of the first piezoelectric bodies 14 and second piezoelectric bodies 15. The acoustic matching section 16 has the function of matching the acoustic impedance between the first piezoelectric bodies 14 and second piezoelectric bodies 15 and the test subject 5. In the acoustic matching section 16, the surface facing the -Z-direction is

understood to be a second surface **16a** (i.e., a surface on the second side of the acoustic matching section **16**). The second surface **16a** is a flat surface.

[0053] The materials for the first electrodes **14a**, the second electrodes **14b**, the first electrodes **15a**, and the second electrodes **15b** are not particularly limited, provided that the materials be electroconductive. It would be possible to a metal such as gold, silver, copper, nickel, or aluminum, an alloy of these metals, or laminated metal.

[0054] A portion going from the substrate **13** to the acoustic matching section **16** is understood to be an ultrasonic device **17**. The ultrasonic device **17** encompasses the substrate **13**, the first piezoelectric bodies **14**, the first electrodes **14a**, the second electrodes **14b**, the second piezoelectric bodies **15**, the first electrodes **15a**, the second electrodes **15b**, and the acoustic matching section **16**.

[0055] An acoustic lens **18** is attached to the second surface **16a**. The acoustic lens **18** is a column lens extending in the X-direction, with which the same as seen from the X-direction is convex. The acoustic lens **18** is also called a rod lens. The ultrasonic waves emitted from the first piezoelectric bodies **14** pass through the acoustic matching section **16** and are incident on the acoustic lens **18**. The ultrasonic waves are focused by the acoustic lens **18**. A material with which the speed of sound of travel through the acoustic lens **18** is slower than the test subject **5** is used for the material of the acoustic lens **18**. For example, where the test subject **5** is a human body, silicone rubber could be used for the material of the acoustic lens **18**.

[0056] FIG. 2A is a schematic diagram for describing the emission and detection of the ultrasonic waves in the ultrasonic sensor. As illustrated in FIG. 2A, ultrasonic waves **21** are emitted from the plurality of first piezoelectric bodies **14**. The emitted ultrasonic waves **21** pass through the acoustic matching section **16** and the acoustic lens **18** and are incident on the test subject **5**. The arrayed first piezoelectric bodies **14** emit the ultrasonic waves **21** with respectively different phases. The location on the test subject **5** that is being examined is understood to be an examination point **5a**. The ultrasonic waves **21** emitted from each of the first piezoelectric bodies **14** are emitted so as to be in the same phase at the examination point **5a**. At the examination point **5a**, the ultrasonic waves **21** interfere constructively, and therefore the same effect as the focusing by the acoustic lens **18** or the like is obtained.

[0057] The ultrasonic waves **21** that are reflected in the examination point **5a** are understood to be reflected waves **21a**. The reflected waves **21a** pass through the test subject **5**, the acoustic lens **18**, and the acoustic matching section **16** and are incident on the second piezoelectric bodies **15**. Because there is a different distance between the examination point **5a** and each of the second piezoelectric bodies **15**, the reflected waves **21a** detected by each of the second piezoelectric bodies **15** will have waveforms of different phases. The sensor drive section **9** computes the intensity of the reflected waves **21a** that are reflected in the examination point **5a** by adjusting the phase of the reflected waves **21a**. The ultrasonic probe **3** modifies the phase of the ultrasonic waves emitted by the first piezoelectric bodies **14** and causes the examination point **5a** to move in the X-direction. Then, the intensity of the reflected waves **21a** at each location is computed. The ultrasonic image apparatus **1** thereby computes the distribution of intensity of the reflected waves **21a** in the interior of the test subject **5**.

[0058] The frequency of the ultrasonic waves **21** emitted by the first piezoelectric bodies **14** is understood to be f_1 . The reflected waves **21a** include sound waves of frequencies that are integer multiples of f_1 . The straightness of travel by the reflected waves **21a** is better when the frequency is higher, and therefore an image obtained by analyzing reflected waves **21a** of a high frequency will have a higher spatial resolution. When the frequency is higher, also, the sound pressure becomes lower, and therefore detection becomes more difficult. Accordingly, efficiently moving the ultrasonic waves higher in the acoustic matching section **16** becomes increasingly important. The second piezoelectric bodies **15** are thinner than the first piezoelectric bodies **14** and therefore are able to detect reflected waves **21a** of a higher frequency than f_1 . Where the frequency detected relative to f_1 is n -fold, then n is referred to as the order of harmonic imaging.

[0059] FIG. 2B is a schematic diagram for describing the relationship between the dimensions of the acoustic matching section and the piezoelectric bodies. As illustrated in FIG. 2B, the acoustic matching section **16** located on the $-Z$ -side of the first piezoelectric bodies **14** is understood to be a first acoustic matching section **16b**. The acoustic matching section **16** that is located on the $-Z$ -side of the second piezoelectric bodies **15** is understood to be a second acoustic matching section **16c**.

[0060] The first surface **13a** and the second surface **16a** are flat surfaces, and are parallel surfaces. The first electrodes **14a** and the first electrodes **15a** are the same thickness; and the second electrodes **14b** and the second electrodes **15b** are the same thickness. The thickness of the first piezoelectric bodies **14** is understood to be a first piezoelectric body thickness **14c** and the thickness of the first acoustic matching section **16b** is understood to be a first acoustic matching section thickness **16d**. The thickness of the second piezoelectric bodies **15** is understood to be a second piezoelectric body thickness **15c** and the thickness of the second acoustic matching section **16c** is understood to be a second acoustic matching section thickness **16e**. At this time, the thickness obtained by adding the first piezoelectric body thickness **14c** and the first acoustic matching section thickness **16d** will be the same thickness as the thickness obtained by adding the second piezoelectric body thickness **15c** and the second acoustic matching section thickness **16e**.

[0061] Next, the selection of the material of the acoustic matching section **16** shall be described, as shall a method of setting the first acoustic matching section thickness **16d** and the second acoustic matching section thickness **16e**. Where the wavelength of the ultrasonic waves **21** traveling through the acoustic matching section **16** is λ , then the first acoustic matching section thickness **16d** and the second acoustic matching section thickness **16e** are set to an odd multiple of $\frac{1}{4}\lambda$. This makes it possible to reduce the amount to which the ultrasonic waves **21** are reflected in the interface. As such, any reduction in sound pressure in passing through the acoustic matching section **16** can be curbed, and the reflected waves **21a** can be efficiently detected.

[0062] A condition for having the first surface **13a** and the second surface **16a** be flat is satisfied. Namely, the thickness obtained when the first piezoelectric body thickness **14c** and the first acoustic matching section thickness **16d** are added is set to the same thickness as the thickness obtained when the second piezoelectric body thickness **15c** and the second acoustic matching section thickness **16e** are added. The first piezoelectric body thickness **14c** is understood to be d_1 , and the first acoustic matching section thickness **16e** is under-

stood to be t_1 . The second piezoelectric body thickness **15c** is understood to be d_2 , and the second acoustic matching section thickness **16e** is understood to be t_2 . At this time, the following formula (1) must be satisfied.

$$d_1 + t_1 = d_2 + t_2 \quad \text{formula (1)}$$

[0063] The materials for the first piezoelectric bodies **14** and the second piezoelectric bodies **15** are understood to both be the same material. The speed of sound in passing through the first piezoelectric bodies **14** and the second piezoelectric bodies **15** is understood to be C_p . The resonant frequency of the first piezoelectric bodies **14** is understood to be f_1 . At this time, the relationship in the following formula (2) holds true.

$$d_1 = C_p / (2 \times f_1) \quad \text{formula (2)}$$

[0064] The resonant frequency detected by the second piezoelectric bodies **15** is understood to be f_2 . f_2 is a frequency of an integer multiple of f_1 , and the integer of the integer multiple is understood to be n . At this time, the relationships in the following formulae (3) to (5) hold true.

$$d_2 = C_p / (2 \times f_2) \quad \text{formula (3)}$$

$$f_2 = n \times f_1 \quad \text{formula (4)}$$

$$d_2 = C_p / (2 \times n \times f_1) \quad \text{formula (5)}$$

[0065] The speed of sound of the ultrasonic waves **21** when passing through the acoustic matching section **16** is understood to be C_s . The frequency of the ultrasonic waves **21** emitted by the first piezoelectric bodies **14** is f_1 . The wavelength of the ultrasonic waves **21** when passing through the first acoustic matching section **16b** is understood to be λ_1 . k_1 is understood to be an odd number. At this time, the relationships in the following formulae (6) to (8) hold true.

$$\lambda_1 = C_s / f_1 \quad \text{formula (6)}$$

$$t_1 = k_1 \times \lambda_1 / 4 \quad \text{formula (7)}$$

$$t_1 = k_1 \times C_s / (4 \times f_1) \quad \text{formula (8)}$$

[0066] The wavelength of the reflected waves **21a** passing through the second acoustic matching section **16c** is understood to be λ_2 . k_2 is understood to be an odd number. At this time, the relationships in the following formulae (9) to (12) hold true.

$$\lambda_2 = C_s / f_2 \quad \text{formula (9)}$$

$$t_2 = k_2 \times \lambda_2 / 4 \quad \text{formula (10)}$$

$$t_2 = k_2 \times C_s / (4 \times f_2) \quad \text{formula (11)}$$

$$t_2 = k_2 \times C_s / (4 \times n \times f_1) \quad \text{formula (12)}$$

[0067] Formula (2), formula (5), formula (8), and formula (12) are plugged into formula (1) and d_1, d_2, t_1 , and t_2 are eliminated. As a result of this operation, the relationship in the following formula (13) holds true. The formula (14) is derived by transforming the formula (13).

$$k_2 = n \times k_1 + 2 \times (i - n - 1) \times C_p / C_s \quad \text{formula (13)}$$

$$C_s = 2 \times (n - 1) \times C_p / (k_2 - n \times k_1) \quad \text{formula (14)}$$

[0068] In formula (14), setting n, k_1, k_2 , and C_p makes it possible to compute C_s . C_s is a value inherent to the material of the acoustic matching section **16**. Selected for the material of the acoustic matching section **16** is a material where the speed of sound matches or approximates the computed value

of C_s . When no suitable material exists, then n, k_1 , and/or k_2 are modified and C_s is recomputed to select a suitable material. The procedure for this operation shall be described next.

[0069] FIG. 3 is a flowchart for describing the procedure for selecting the material of the acoustic matching section. A step S1 corresponds to a step for “determining the order n of harmonic imaging”. In this step, the order n of harmonic imaging is set. The order n is an integer 2 or higher. Next is a transition to a step S2. The step S2 corresponds to a step for “setting $k_1 = 1$ ”. This step is a step where the initial value of k_1 is set to 1. Next is a transition to a step S3.

[0070] The step S3 corresponds to a step for “setting the initial value of k_2 a minimum odd number greater than $n \times k_1$ ”. This step is a step where the initial value of k_2 is set. When $n = 2$ and $k_1 = 1$, then k_2 is set to $= 3$. When $n = 3$ and $k_1 = 1$, then k_2 is set to $= 5$. Next is a transition to a step S4. The step S4 corresponds to a step for “finding C_s where $C_p = 4000$ m/s”. The material for the first piezoelectric bodies **14** and the second piezoelectric bodies **15** is understood to be PZT. C_p is the speed of sound in PZT. This step is a step where n, k_1, k_2 , and C_p are plugged into the formula (13) and C_s is computed. Next is a transition to a step S5.

[0071] The step S5 corresponds to a step for determining “is there any acoustic matching material that has the C_s value needed?”. This step is a step where the acoustic matching material is set. When a suitable acoustic matching material can be set, then this corresponds to YES, and the procedure for selecting the material for the acoustic matching section **16** is concluded. When a suitable acoustic matching material cannot be set, then this corresponds to NO, and the flow next transitions to a step S6.

[0072] The step S6 corresponds to a step for determining “is $k_2 > 20$?”. The upper limit of k_2 is set to 20, and this step is a step where the question of whether the value of k_2 exceeds the upper limit is determined. When the value of k_2 exceeds the upper limit, then this corresponds to YES, and the flow next proceeds to a step S8. When the value of k_2 does not exceed the upper limit, then this corresponds to NO, and the flow next proceeds to a step S7.

[0073] The step S7 corresponds to a step for setting “ $k_2 = k_2 + 2$ ”. This step is a step where the integer 2 is added to k_2 . k_2 after the addition will be an odd number. Next is a transition to the step S4.

[0074] The step S8 corresponds to a step for determining whether “ $k_1 > 10$?”. The upper limit of k_1 is set to 10, and this step is a step where the question of whether the value of k_1 exceeds the upper limit is determined. When the value of k_1 exceeds the upper limit, then this corresponds to YES, and the procedure for setting the material of the acoustic matching section **16** is concluded. When the value of k_1 does not exceed the upper limit, then this corresponds to NO, and the flow next proceeds to a step S9. In a case where $k_2 > 20$ or where $k_1 > 10$, then the thickness of the acoustic matching section **16** ends up being dominant over the thickness of the first piezoelectric bodies **14** and the second piezoelectric bodies **15**. For this reason, the concern is that this is no longer conducive to reducing the scale of the ultrasonic probe **3**, and it does not signify that the acoustic matching conditions are lost.

[0075] The step S9 corresponds to a step for setting “ $k_1 = k_1 + 2$ ”. This step is a step where the integer 2 is added to k_1 . k_1 after the addition will be an odd number. Next is a transition to the step **3**. This concludes the description of the procedure for selecting the material for the acoustic matching section **16**. When a suitable material for the acoustic match-

ing section 16 cannot be selected by carrying out $n=2$, then the material for the acoustic matching section 16 is selected by setting $n=3$ or higher.

[0076] FIG. 4 is a drawing illustrating the result of material selection for when the order n of harmonic imaging $=2$. As illustrated in FIG. 4, PZT is selected for the material for the first piezoelectric bodies 14 and the second piezoelectric bodies 15, and $n=2$ is selected. When $k_1=1$ and $k_2=3$, then $C_s=8000$ m/s. The materials corresponding to this C_s are limited to special metals, such as beryllium. The acoustic impedance of the acoustic matching section 16 needs to be an acoustic impedance that is intermediate between the acoustic impedance of the test subject 5 and the acoustic impedance of PZT. Beryllium is not suitable because the condition for acoustic impedance is not satisfied by metal when the test subject 5 is a human body.

[0077] When $k_1=1$ and $k_2=5$, then $C_s=2667$ m/s. One available material corresponding to this C_s is a polymer material. A polymer material is indicative of, for example, a synthetic fiber, synthetic resin, or synthetic rubber. Polymer materials have a high acoustic impedance and satisfy the condition for acoustic impedance when the first piezoelectric bodies 14 and the second piezoelectric bodies 15 are bulk-type, and can therefore be used. When the first piezoelectric bodies 14 and the second piezoelectric bodies 15 are thin-film-type, then the condition for acoustic impedance is not satisfied, and therefore polymer materials cannot be used.

[0078] When $k_1=1$ and $k_2=7$, then $C_s=1600$ m/s. One available material corresponding to this C_s is a natural rubber. A natural rubber satisfies the condition for acoustic impedance and also has favorable workability, and can therefore be used.

[0079] When $k_1=1$ and $k_2=9$, then $C_s=1143$ m/s. One available material corresponding to this C_s is a silicone resin. A silicone resin satisfies the condition for acoustic impedance and also has favorable workability, and therefore can be used as the material for the acoustic matching section 16.

[0080] When $k_1=3$ and $k_2=7$, then $C_s=8000$ m/s. Materials corresponding to this C_s are limited to special metals such as beryllium. Beryllium is not suitable because the condition for acoustic impedance is not satisfied by metal when the test subject 5 is a human body. When $k_1=3$ and $k_2=9$, then $C_s=2667$ m/s. One available material corresponding to this C_s is a polymer material.

[0081] FIG. 5 is a drawing illustrating the result of material selection for when the order n of harmonic imaging $=3$. As illustrated in FIG. 5, PZT is selected for the material for the first piezoelectric bodies 14 and the second piezoelectric bodies 15, and $n=3$ is selected. When $k_1=1$ and $k_2=5$, then $C_s=8000$ m/s. Materials corresponding to this C_s are limited to special metals such as beryllium. The special metals are not suitable because the condition for acoustic impedance is not satisfied.

[0082] When $k_1=1$ and $k_2=7$, then $C_s=4000$ m/s. One available material corresponding to this C_s is ceramics. Ceramics have a high acoustic impedance and satisfy the condition for acoustic impedance when the first piezoelectric bodies 14 and the second piezoelectric bodies 15 are bulk-type, and can therefore be used. When the first piezoelectric bodies 14 and the second piezoelectric bodies 15 are thin-film-type, then the condition for acoustic impedance is not satisfied, and therefore ceramics cannot be used. Ceramics

necessitate a step for polishing in order to adjust the thickness after sintering, and are therefore not suitable in terms of workability.

[0083] When $k_1=1$ and $k_2=9$, then $C_s=2667$ m/s. One available material corresponding to this C_s is a polymer material. When $k_1=1$ and $k_2=11$, then $C_s=2000$ m/s. One available material corresponding to this C_s is a polyethylene resin. A polyethylene resin satisfies the condition for acoustic impedance and also has favorable workability, and can therefore be used.

[0084] When $k_1=3$ and $k_2=11$, then $C_s=8000$ m/s. Materials corresponding to this C_s are limited to special metals such as beryllium. The special metals are not suitable because the condition for acoustic impedance is not satisfied. When $k_1=3$ and $k_2=13$, then $C_s=4000$ m/s. One available material corresponding to this C_s is ceramics. When $k_1=3$ and $k_2=15$, then $C_s=2667$ m/s. One available material corresponding to this C_s is a polymer material.

[0085] When $n=2$, then natural rubbers and silicone resins can be favorably used for the acoustic matching section 16. When $n=3$, then polyethylene resins can be favorably used for the acoustic matching section 16. At this time, the acoustic waves 21 can be efficiently passed through the acoustic matching section 16 even though the first surface 13a and the second surface 16a have been flattened.

[0086] Next, a method of manufacturing the ultrasonic sensor 8 described above shall be described, with reference to FIGS. 6 and 7A to 7H. FIG. 6 is a flowchart of the method of manufacturing the ultrasonic sensor, and FIGS. 7A to 7H are schematic diagrams for describing the method of manufacturing the ultrasonic sensor. In the flowchart in FIG. 6, the step S11 corresponds to an electrode plating step. This is a step where the first electrodes 14a and the second electrodes 14b are formed of the material for the first piezoelectric bodies 14, and the first electrodes 15a and the second electrodes 15b are formed of the material for the second piezoelectric bodies 15. Next is a transition to a step S12. The step S12 corresponds to a piezoelectric body division step. This step is a step where rod-shaped piezoelectric bodies are divided and the first piezoelectric bodies 14 and the second piezoelectric bodies 15 are formed. Next is a transition to a step S13.

[0087] The step S13 corresponds to a piezoelectric body adhesion step. This step is a step where the first piezoelectric bodies 14 and the second piezoelectric bodies 15 are adhered to the substrate 13. Next is a transition to a step S14. The step S14 corresponds to a matching section application step. This step is a step where the material for the acoustic matching section 16 is applied. Next is a transition to a step S15. The step S15 corresponds to a flattening step. This step is a step where the upper surface of the applied material for the acoustic matching section 16 is flattened. Next is a transition to a step S16. The step S16 corresponds to a matching section solidification step. This step is a step where the material for the acoustic matching section 16 is solidified. Next is a transition to a step S17. The step S17 corresponds to a lens adhesion step. This is a step where the acoustic lens 18 is adhered to the acoustic matching section 16. The steps above complete the ultrasonic sensor 8.

[0088] Next, the method of manufacture shall be described in greater detail, with reference to FIGS. 7A to 7H and in correspondence with steps illustrated in FIG. 6. FIGS. 7A and 7B are drawings corresponding to the electrode plate step in step S11. As illustrated in FIGS. 7A and 7B, a first piezoelectric body plate 22 and a second piezoelectric body plate 23 are

prepared in the step S11. The first piezoelectric body plate 22 is the material for the first piezoelectric bodies 14, and the second piezoelectric body plate 23 is the material for the second piezoelectric bodies 15.

[0089] Metal films 22a are formed on opposing surfaces of the first piezoelectric body plate 22. Electroless plating or sputtering can be used as a method of forming the metal films 22a. The metal films 22a may also be thickened with electroplating. Likewise, metal films 23a are formed on opposing surfaces of the second piezoelectric body plate 23. A method similar to the method of forming the metal films 22a can be used as a method of forming the metal films 23a.

[0090] FIGS. 7C and 7D are drawings corresponding to the piezoelectric body division step in the step 12. As illustrated in FIG. 7C, the first piezoelectric body plate 22 is cut into rods in the step S12. A dicing device or wire saw cutting machine can be used in a method of cutting the first piezoelectric body plate 22. The first piezoelectric body plate 22 is cut and one of the metal films 22a becomes the first electrodes 14a while the other becomes the second electrodes 14b. Likewise, as illustrated in FIG. 7D, the second piezoelectric body plate 23 is cut into rods. A device similar to the device that cuts the first piezoelectric body plate 22 can be used for a device for cutting the second piezoelectric body plate 23. The second piezoelectric body plate 23 is cut and one of the metal films 23a becomes the first electrodes 15a while the other becomes the second electrodes 15b.

[0091] FIG. 7E is a drawing corresponding to the piezoelectric body adhesion step in the step S13. As illustrated in FIG. 7E, the first piezoelectric bodies 14 and the second piezoelectric bodies 15 are arrayed and adhered onto the substrate 13 in the step S13. The first piezoelectric bodies 14 and the second piezoelectric bodies 15 are arranged alternately side by side with one another. At this time, the first surface 13a of the substrate 13 is a flat surface, and therefore the first surface 13a is a surface that is easy to form. Then, because the first surface 13a of the substrate 13 is a flat surface, the first piezoelectric bodies 14 and the second piezoelectric bodies 15 can be easily arranged thereon.

[0092] FIG. 7F is a drawing corresponding to the matching section application step in the step S14. As illustrated in FIG. 7F, an acoustic matching section material 24 is applied by being overlaid onto the first piezoelectric bodies 14 and the second piezoelectric bodies 15 in the step S14. The acoustic matching section material 24 is what is obtained when a solvent is added to the material that was set in the step S5. The solvent is added to the acoustic matching section material 24 so as to facilitate the application, and the viscosity of the acoustic matching section material 24 is adjusted.

[0093] FIG. 7G is a drawing corresponding to the flattening step in the step S15 and the matching section solidification step in the step S16. As illustrated in FIG. 7G, the upper surface of the acoustic matching section material 24 is flattened in the step S15. The acoustic matching section material 24 is a liquid that is viscous to an appropriate degree. A method of scraping the upper surface of the applied acoustic matching section material 24 with a straight plate can be used as a method of flattening. The plate with which the scraping is done is called a squeegee.

[0094] Next, the acoustic matching section material 24 is dried and the solvent that is included in the acoustic matching section material 24 is evaporated in the step S16. To dry the acoustic matching section material 24, using a temperature-adjustable thermostatic chamber makes it possible to dry with

excellent quality. The temperature and duration of drying are set in accordance with the material for the acoustic matching section material 24. As a result, the acoustic matching section material 24 solidifies and becomes the acoustic matching section 16. The second surface 16a of the acoustic matching section 16 becomes a flat surface.

[0095] FIG. 7H is a drawing corresponding to the lens adhesion step in the step S17. As illustrated in FIG. 7H, the acoustic lens 18 is adhered to the acoustic matching section 16 in the step S17. Because the second surface 16a of the acoustic matching section 16 has been made into a flat surface, the acoustic matching section 16 and the acoustic lens 18 can be easily adhered to one another such that a spacing does not form between the acoustic matching section 16 and the acoustic lens 18. The adhesive material is selected in accordance with the acoustic matching section 16. The steps above complete the ultrasonic sensor 8.

[0096] As described above, according to the present embodiment, the following effects are present.

[0097] (1) According to the present embodiment, the first surface 13a of the substrate 13 is a flat surface. As such, the shape facilitates processing compared to when unevenness is provided to the first surface 13a of the substrate 13. Moreover, the second surface 16a of the acoustic matching section 16 is also a flat surface. As such, the acoustic matching section 16 has a shape that facilitates processing compared to when unevenness is provided to the second surface 16a. As a result, the ultrasonic device 17 can be manufactured at high productivity.

[0098] (2) According to the present embodiment, as illustrated with the formula (4), f_2 , which is the resonant frequency of the second piezoelectric bodies 15, is an integer multiple of f_1 , which is the resonant frequency of the first piezoelectric bodies 14. As such, the first piezoelectric bodies 14 output ultrasonic waves, and the second piezoelectric bodies 15 can detect the n-th order high frequency of the reflected waves 21a that are reflected in the test subject 5. Having the thickness d1 of the first piezoelectric bodies be as illustrated by the formula (2) makes it possible to have the resonant frequency of the first piezoelectric bodies 14 be f_1 . Likewise, having the thickness d2 of the second piezoelectric bodies 15 be as illustrated by the formula (3) makes it possible to have the resonant frequency of the second piezoelectric bodies be f_2 .

[0099] (3) According to the present embodiment, there is a relationship $\lambda = Cs/f$, where λ is the wavelength of the ultrasonic waves 21 traveling through the acoustic matching section 16 and f is the frequency. Then, the formula (8) illustrates $t_1 = k_1 > \lambda/4$, and the formula (11) illustrates $t_2 = k_2 \times \lambda/4$. In other words, the ultrasonic waves 21 traveling through the acoustic matching section 16 are an odd multiple of $\lambda/4$. This curbs any incidence where the ultrasonic waves 21 traveling through the acoustic matching section 16 would cancel each other out with the ultrasonic waves 21 reflected in the interface of the acoustic matching section 16. As such, the acoustic matching section 16 can allow the ultrasonic waves 21 to travel through efficiently.

[0100] (4) According to the present embodiment, as illustrated by the formula (1), the thickness obtained by adding the first piezoelectric body thickness 14c and the first acoustic matching section thickness 16d will be the same thickness as the thickness obtained by adding the second piezoelectric body thickness 15c and the second acoustic matching section thickness 16e. By so doing, when the first surface 13a on

which the first piezoelectric bodies **14** and the second piezoelectric bodies **15** are installed in the substrate **13** is flat, then the second surface **16a** of the acoustic matching section **16** will also be flat. Then, C_s is computed by setting n , k_1 , k_2 , and C_p as illustrated in the formula (14). Having the material of the acoustic matching section **16** be a material that corresponds to the computed C_s makes it possible to manufacture at high productivity an ultrasonic device **17** with which the ultrasonic waves **21** travel efficiently through the acoustic matching section **16**.

[0101] (5) According to the present embodiment, C_s will be 1600 m/s when $n=2$, $k_1=1$, $k_2=7$, and $C_p=4000$ m/s in the formula (14). Then, a natural rubber fits for when $C_s=1600$ m/s. Natural rubbers have excellent workability. As such, using a natural rubber for the material of the acoustic matching section **16** makes it possible to manufacture at high productivity an ultrasonic device **17** with which the ultrasonic waves **21** travel efficiently through the acoustic matching section **16**.

[0102] (6) According to the present embodiment, C_s will be 1143 m/s when $n=2$, $k_1=1$, $k_2=9$, and $C_p=4000$ m/s in the formula (14). Then, a silicone resin fits for when $C_s=1143$ m/s. Silicone resins have excellent workability. As such, using a silicone resin for the material of the acoustic matching section **16** makes it possible to manufacture at high productivity an ultrasonic device **17** with which the ultrasonic waves **21** travel efficiently through the acoustic matching section **16**.

[0103] (7) According to the present embodiment, C_s will be 2000 m/s when $n=3$, $k_1=1$, $k_2=11$, and $C_p=4000$ m/s in the formula (14). Then, a polyethylene resin fits for when $C_s=2000$ m/s. Polyethylene resins have excellent workability. As such, using a polyethylene resin for the material of the acoustic matching section **16** makes it possible to manufacture at high productivity an ultrasonic device **17** with which the ultrasonic waves **21** travel efficiently through the acoustic matching section **16**.

[0104] (8) According to the present embodiment, the first surface **13a** of the substrate **13** is a flat surface. As such, the first surface **13a** is easier to form compared to when there is unevenness. Then, the first piezoelectric bodies **14** and the second piezoelectric bodies **15** are installed onto the first surface **13a**. The first piezoelectric bodies **14** and the second piezoelectric bodies **15** can be installed easily because the first surface **13a** is a flat surface. The second surface **16a** of the acoustic matching section **16** is a flat surface. As such, the second surface **16a** and the acoustic lens **18** can be easily adhered to one another such that a spacing does not form between the second surface **16a** and the acoustic lens **18**.

Second Embodiment

[0105] Next, as regards one embodiment of an ultrasonic sensor having a characteristic structure, FIG. 8 is a schematic perspective view illustrating the structure of an ultrasonic sensor. The present embodiment differs from the first embodiment in the arrangement of the first piezoelectric bodies **14** and the second piezoelectric bodies **15** illustrated in FIG. 1B. Matters where the present embodiment is the same as the first embodiment are omitted from the description here.

[0106] Namely, in the present embodiment, as illustrated in FIG. 8, an ultrasonic sensor **27** is provided with the substrate **13**, and first piezoelectric bodies **28** and second piezoelectric bodies **29** are arranged on the first surface **13a**. Because the first surface **13a** is a flat surface, the first piezoelectric bodies **28** and the second piezoelectric bodies **29** are easily arranged

on the first surface **13a**. The shape of the first piezoelectric bodies **28** is a prism, and first electrodes **28a** are installed on a surface of the first piezoelectric bodies **28** facing the substrate **13** side. Second electrodes **28b** are installed on a surface of the opposite side to the first electrodes **28a** in the first piezoelectric bodies **28**.

[0107] The shape of the second piezoelectric bodies **29** is also a prism, and the length of the second piezoelectric bodies **29** in the Y-direction is the same length as that of the first piezoelectric bodies **28**. The length of the X-direction width of the second piezoelectric bodies **29** is also the same length as that of the first piezoelectric bodies **28**. The length of the Z-direction thickness of the second piezoelectric bodies **29** is a shorter length than that of the first piezoelectric bodies **28**. First electrodes **29a** are installed on a surface of the second piezoelectric bodies **29** facing the substrate **13** side. Second electrodes **29b** are installed on a surface of the opposite side to the first electrodes **29a** in the second piezoelectric bodies **29**.

[0108] The first piezoelectric bodies **28** are arranged on the Y-direction side on the first surface **13a**, and the second piezoelectric bodies **29** are arranged on the -Y-direction side. The first piezoelectric bodies **28** and the second piezoelectric bodies **29** are arrayed side by side in the X-direction.

[0109] For the sake of simplifying the drawings, the depicted first piezoelectric bodies **28** and second piezoelectric bodies **29** are arranged each in increments of eight. The numbers of first piezoelectric bodies **28** and second piezoelectric bodies **29** are not particularly limited. When the numbers are greater, the examination range can be widened by a commensurate amount. Alternatively, the resolution can be increased. In the present embodiment, for example, there are 256 of the first piezoelectric bodies **28** and the second piezoelectric bodies **29**, each.

[0110] An acoustic matching section **30** is installed on the -Z-side of the first piezoelectric bodies **28** and the second piezoelectric bodies **29**. The material of the acoustic matching section **30** is the same material as that of the acoustic matching section **16** in the first embodiment. The substrate **13**, the first piezoelectric bodies **28**, the second piezoelectric bodies **29**, the acoustic matching section **30**, and the like constitute an ultrasonic device **31**. The acoustic lens **18** is installed on the acoustic matching section **30**. A second surface **30a**, which is a surface of the acoustic matching section **30** that faces the acoustic lens **18**, is a flat surface. As such, the second surface **30a** and the acoustic lens **18** can be easily adhered to one another such that a spacing does not form between the acoustic matching section **30** and the acoustic lens **18**.

[0111] The thickness of the first piezoelectric bodies **28** is the same thickness as that of the first piezoelectric body thickness **14c** of the first piezoelectric bodies **14** in the first embodiment. The material of the first piezoelectric bodies **28** is the same material as that of the first piezoelectric bodies **14**. Likewise, the thickness of the second piezoelectric bodies **29** is also the same thickness as that of the second piezoelectric body thickness **15c** of the second piezoelectric bodies **15** in the first embodiment. The material of the second piezoelectric bodies **29** is the same material as that of the second piezoelectric bodies **15**.

[0112] The material of the acoustic matching section **30** is the same material as that of the acoustic matching section **16** in the first embodiment. In the acoustic matching section **30**, the thickness of the location that faces the first piezoelectric

bodies 28 is the same thickness as that of the first acoustic matching section thickness 16d, and the thickness of the location that faces the second piezoelectric bodies 29 is the same thickness as that of the second acoustic matching section thickness 16e.

[0113] As such, the ultrasonic sensor 27 can emit the ultrasonic waves 21 efficiently. It then becomes possible to efficiently detect the higher-order reflected waves 21a that are reflected by the test subject 5.

Third Embodiment

[0114] Next, an embodiment of manufacturing an ultrasonic sensor shall be described, with reference to FIGS. 9 and 10. The present embodiment differs from the first embodiment in that the first piezoelectric bodies 14 and the second piezoelectric bodies 15 are changed from bulk-type to thin-film-type. Matters where the present embodiment is the same as the first embodiment are omitted from the description here.

[0115] FIG. 9A is a schematic lateral cross-sectional view illustrating a structure of an ultrasonic sensor. As illustrated in FIG. 9A, an ultrasonic sensor 34 is provided with a backing substrate 35. The backing substrate 35 is a site corresponding to the substrate 13 of the first embodiment. A substrate 36 is installed onto the backing substrate 35. The substrate 36 is not particularly limited, provided that the substrate be one with heat resistance, such as a silicon substrate or a glass substrate. In the present embodiment, for example, a silicon substrate is used for the substrate 36.

[0116] In the substrate 36, first electrodes are installed on an opposite side of the backing substrate 35. Between the substrate 36 and the first electrodes 37, there is an insulating film (not shown) that is formed. The insulating film could be, for example, a film of silicon dioxide or silicon nitride. The materials for the first electrodes 37 are layers of iridium, iridium oxide, and platinum stacked in the stated order from the substrate 36 side. Iridium, iridium oxide, and platinum are endowed with functions as an orientation control, a reducing gas barrier, and a seed layer, respectively.

[0117] Onto the first electrodes 37 are first piezoelectric bodies 38 and second piezoelectric bodies 39 arranged, in alternation. The first piezoelectric bodies 38 and the second piezoelectric bodies 39 are constituted of PZT. Second electrodes 38b are installed on the first piezoelectric bodies 38, and second electrodes 39b are installed on the second piezoelectric bodies 39. An acoustic matching section 40 is installed onto the second electrodes 38b and second electrodes 39b. An acoustic lens 41 is furthermore installed onto the acoustic matching section 40. The materials for the second electrodes 38b and the second electrodes 39b are layers of platinum, iridium oxide, and iridium stacked in the stated order from the first piezoelectric body 38 and second piezoelectric body 39 side.

[0118] The first piezoelectric bodies 38, the second piezoelectric bodies 39, the acoustic matching section 40, and the acoustic lens 41 are sites corresponding to the first piezoelectric bodies 14, the second piezoelectric bodies 15, the acoustic matching section 16, and the acoustic lens 18, respectively, in the first embodiment. The thicknesses of the first piezoelectric bodies 38, the second piezoelectric bodies 39, and the acoustic matching section 40 are set in accordance with the formulae (1) to (14). As such, it becomes possible to efficiently emit the ultrasonic waves 21 and to efficiently detect the reflected waves 21a.

[0119] A first surface 36a, which is the surface of the substrate 36 on which the first electrodes 37 are installed, is a flat surface, making the surface easy to process. A second surface 40a, which is a surface that faces the acoustic lens 41 in the acoustic matching section 40, is also a flat surface, making the surface easy to process. Because the second surface 40a is flat, it becomes possible to easily bond the acoustic matching section 40 and the acoustic lens 41 together such that a spacing is not formed between the acoustic matching section 40 and the acoustic lens 41. The configuration from the backing substrate 35 to the acoustic matching section 40 is an ultrasonic device 42.

[0120] Next, a method of manufacturing the ultrasonic sensor 34 described above shall be described with reference to FIGS. 9B and 10A to 10F. FIG. 9B is a flowchart for a method of manufacturing an ultrasonic sensor, and FIGS. 10A to 10F are schematic diagrams for describing a method of manufacturing an ultrasonic sensor. In the flowchart in FIG. 9B, a step S21 corresponds to a first electrode formation step. This is a step where the insulating film and the first electrodes 37 are formed on the first surface 36a of the substrate 36. Next is a transition to a step S22. The step S22 corresponds to a piezoelectric body formation step. This step is a step where the first piezoelectric bodies 38 and the second piezoelectric bodies 39 are formed on the first electrodes 37. Next is a transition to a step S23.

[0121] The step S23 corresponds to a second electrode formation step. This step is a step where the second electrodes 38b are formed on the first piezoelectric bodies 38 and the second electrodes 39b are formed on the second piezoelectric bodies 39. Next is a transition to a step S24. The step S24 corresponds to a matching section application step. This step is a step where the material for the acoustic matching section 40 is applied. Next is a transition to a step S25. The step S25 corresponds to a flattening step. This step is a step where the upper surface of the applied material for the acoustic matching section 40 is flattened. Next is a transition to a step S26. The step S26 corresponds to a matching section solidification step. This step is a step where the material for the acoustic matching section 40 is solidified. Next is a transition to a step S27. The step S27 corresponds to a substrate adhesion step. This step is a step where the substrate 36 is adhered to the backing substrate 35. Next is a transition to a step S28. The step S28 corresponds to a substrate division step. This step is a step where the backing substrate 35 and the substrate 36 are divided. Next is a transition to a step S29. The step S29 corresponds to a lens adhesion step. This is a step where the acoustic lens 41 is adhered to the acoustic matching section 40. The steps above complete the ultrasonic sensor 34.

[0122] Next, the method of manufacture shall be described in greater detail, with reference to FIGS. 10A to 10F and in correspondence with steps illustrated in FIG. 9B. FIG. 10A is a drawing corresponding to the first electrode formation step in the step S21. As illustrated in FIG. 10A, in the step S21, first, a mother substrate 43 is prepared. The mother substrate 43 is large enough to allow for a plurality of the substrates 36 to be arranged. The mother substrate 43 is oxidized to form an oxide film. The oxide film functions as the insulating film. Next, a solid film composed of the materials for the first electrodes 37 is formed on the mother substrate 43. Sputtering can be used for the solid film. Next, photolithography is used to pattern the solid film and form the first electrodes 37.

[0123] FIG. 10B is a drawing corresponding to the piezoelectric body formation step in the step S22. As illustrated in

FIG. 10B, the first piezoelectric bodies 38 and the second piezoelectric bodies 39 are formed on the first electrodes 37. The first piezoelectric bodies 38 and the second piezoelectric bodies 39 are formed, for example, by repeatedly performing film formation using sputtering or a sol-gel method and then patterning.

[0124] FIG. 10C is a drawing corresponding to the second electrode formation step in the step S23. As illustrated in FIG. 10C, the second electrodes 38b are formed on the first piezoelectric bodies 38, and the second electrodes 39b are formed on the second piezoelectric bodies 39. The second electrodes 38b and the second electrodes 39b are formed using photolithography on a solid film formed by sputtering.

[0125] FIG. 10D is a drawing corresponding to the matching section application step in the step S24. As illustrated in FIG. 10D, the acoustic matching section material 44 is applied overlaid onto the first piezoelectric bodies 38 and second piezoelectric bodies 39 in the step S24. The acoustic matching section material 44 is what is obtained when a solvent is added to the material that was set in the step S5. The solvent is added to the acoustic matching section material 44 so as to facilitate the application, and the viscosity of the acoustic matching section material 44 is adjusted.

[0126] FIG. 10E is a drawing corresponding to the flattening step in the step S25, the matching section solidification step in the step S26, the substrate adhesion step in the step S27, and the substrate division step in the step S28. As illustrated in FIG. 10E, the upper surface of the acoustic matching section material 44 is flattened in the step S25. The acoustic matching section material 44 is a liquid that is viscous to an appropriate degree. A method of scraping the upper surface of the applied acoustic matching section material 44 with a straight plate can be used as a method of flattening.

[0127] Next, the acoustic matching section material 44 is dried and the solvent that is included in the acoustic matching section material 44 is evaporated in the step S26. To dry the acoustic matching section material 44, using a temperature-adjustable thermostatic chamber makes it possible to dry with excellent quality. The temperature and duration of drying are set in accordance with the material for the acoustic matching section material 44. As a result, the acoustic matching section material 44 solidifies and becomes the acoustic matching section 40. The second surface 40a of the acoustic matching section 40 is a flat surface.

[0128] Next, in the step S27, a large backing substrate 45 is prepared. The large backing substrate 45 is large enough that a plurality of backing substrates 35 can be arranged thereon. Then, the large backing substrate 45 and the mother substrate 43 are adhered together. Then, in the step S28, the large backing substrate 45 and the mother substrate 43 are divided with a dicer. The mother substrate 43 is divided and becomes the substrates 36, and the large backing substrate 45 is divided and becomes the backing substrates 35. The backing substrates 35 and the substrates 36 are the size of the ultrasonic sensor 34.

[0129] FIG. 10F is a drawing corresponding to the lens adhesion step in the step S29. As illustrated in FIG. 10F, the acoustic lens 41 is adhered to the acoustic matching section 40 in the step S29. Because the second surface 40a of the acoustic matching section 40 is flat, it becomes possible to easily bond the acoustic matching section 40 and the acoustic lens 41 together such that a spacing is not formed between the acoustic matching section 40 and the acoustic lens 41. The

adhesive material is selected in accordance with the acoustic matching section 40. The steps above complete the ultrasonic sensor 34.

[0130] As described above, according to the present embodiment, the following effects are present.

[0131] (1) According to the present embodiment, the first piezoelectric bodies 38 and the second piezoelectric bodies 39 are formed using photolithography. As such, a large number of the first piezoelectric bodies 38 and the second piezoelectric bodies 39 can be formed on a narrow surface area. As such, the ultrasonic sensor 34 can be made into a high-resolution sensor.

[0132] The present invention is in no way limited to the embodiments described above, and it would also be possible for a variety of modifications or improvements to be added by a person having ordinary skill in the art without departing from the teachings of the present invention. Modification examples shall be described below.

Modification Example 1

[0133] In the first embodiment, the ultrasonic sensor 8 was installed onto the ultrasonic probe 3 of the ultrasonic image apparatus 1. The ultrasonic sensor 27 of the second embodiment may also be installed onto the ultrasonic probe 3. The ultrasonic sensor 34 of the third embodiment may be installed onto the ultrasonic probe 3. At this time, the ultrasonic sensors 27, 34 would still be able to efficiently emit the ultrasonic waves 21 and efficiently receive the reflected waves 21a.

Modification Example 2

[0134] In the first embodiment, acoustic matching sections 16 for a case where the order n of harmonic imaging=2 and a case where $n=3$ were selected. n may also be 4 or higher. A higher order for n means that the resolution at which the reflected waves 21a are detected can be raised.

GENERAL INTERPRETATION OF TERMS

[0135] 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 $\pm 5\%$ of the modified term if this deviation would not negate the meaning of the word it modifies.

[0136] 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 illustra-

tion 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 device comprising:

a substrate having a first surface, the first surface being a flat surface;

a first piezoelectric body disposed on the first surface of the substrate;

a second piezoelectric body disposed on the first surface of the substrate, the second piezoelectric body having a different thickness from a thickness of the first piezoelectric body as measured from the first surface of the substrate; and

an acoustic matching section disposed on the first piezoelectric body and the second piezoelectric body, the acoustic matching section having a first side facing the first piezoelectric body and the second piezoelectric body, and a second side opposite from the first side, a surface of the acoustic matching section on the second side being a flat surface parallel with the first surface of the substrate.

2. The ultrasonic device according to claim 1, wherein formulae (1) to (7) are satisfied, where C_p is a speed of sound in the first piezoelectric body and the second piezoelectric body, C_s is a speed of sound in the acoustic matching section, f_1 is a resonant frequency of the first piezoelectric body, f_2 is a resonant frequency of the second piezoelectric body, d_1 is the thickness of the first piezoelectric body, d_2 is the thickness of the second piezoelectric body, t_1 is a thickness of the acoustic matching section as measured from a surface of the first piezoelectric body, t_2 is a thickness of the acoustic matching section as measured from a surface of the second piezoelectric body, n is an integer, and k_1 and k_2 are odd numbers,

$$f_2 = n \times f_1 \quad \text{formula (1)}$$

$$d_1 = C_p / (2 \times f_1) \quad \text{formula (2)}$$

$$d_2 = C_p / (2 \times f_2) \quad \text{formula (3)}$$

$$t_1 = k_1 \times C_s / (4 \times f_1) \quad \text{formula (4)}$$

$$t_2 = k_2 \times C_s / (4 \times f_2) \quad \text{formula (5)}$$

$$d_1 + t_1 = d_2 + t_2 \quad \text{formula (6)}$$

$$C_s = 2 \times (n-1) \times C_p / (k_2 - n \times k_1) \quad \text{formula (7)}$$

3. The ultrasonic device according to claim 2, wherein the acoustic matching section is made of natural rubber.

4. The ultrasonic device according to claim 2, wherein the acoustic matching section is made of silicone resin.

5. The ultrasonic device according to claim 2, wherein the acoustic matching section is made of polyethylene resin.

6. A method of manufacturing an ultrasonic device comprising:

forming a first piezoelectric body and a second piezoelectric body on a flat first surface of a substrate; and

forming an acoustic matching section having a first side facing the first piezoelectric body and the second piezoelectric body, and a second side opposite from the first side, so that a surface of the acoustic matching section on the second side is a flat surface parallel with the first surface of the substrate.

7. An ultrasonic probe comprising:

an ultrasonic device; and

a drive section configured and arranged to drive the ultrasonic device,

the ultrasonic device including

a substrate having a first surface, the first surface being a flat surface,

a first piezoelectric body disposed on the first surface of the substrate,

a second piezoelectric body disposed on the first surface of the substrate, and

an acoustic matching section disposed on the first piezoelectric body and the second piezoelectric body, the acoustic matching section having a first side facing the first piezoelectric body and the second piezoelectric body, and a second side opposite from the first side, a surface of the acoustic matching section on the second side being a flat surface parallel with the first surface of the substrate.

8. An ultrasonic diagnostic apparatus comprising:

an ultrasonic device configured and arranged to emit ultrasonic waves at a test subject and to detect ultrasonic waves that are reflected in the test subject;

a drive section configured and arranged to drive the ultrasonic device;

a reflection distribution computation section configured to compute distribution of reflectance of ultrasonic waves in the test subject from the ultrasonic waves detected by the ultrasonic device; and

a display section configured and arranged to display an image based on the distribution of reflectance of ultrasonic waves in the test subject as computed by the reflection distribution computation section,

the ultrasonic device including

a substrate having a first surface, the first surface being a flat surface,

a first piezoelectric body disposed on the first surface of the substrate,

a second piezoelectric body disposed on the first surface of the substrate, and

an acoustic matching section disposed on the first piezoelectric body and the second piezoelectric body, the acoustic matching section having a first side facing the first piezoelectric body and the second piezoelectric body, and a second side opposite from the first side, a surface of the acoustic matching section on the second side being a flat surface parallel with the first surface of the substrate.

* * * * *

专利名称(译)	超声波装置，超声波探头，超声波诊断装置以及超声波装置的制造方法		
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摘要(译)

超声波装置包括基板，第一压电体，第二压电体和声匹配部。基板具有第一表面，该第一表面是平坦表面。第一压电体设置在基板的第一表面上。第二压电体设置在基板的第一表面上。从基板的第一表面测量，第二压电体具有与第一压电体的厚度不同的厚度。声匹配部分设置在第一压电体和第二压电体上。声匹配部分具有面向第一压电体和第二压电体的第一侧，以及与第一侧相对的第二侧。第二侧上的声匹配部分的表面是与基板的第一表面平行的平坦表面。

