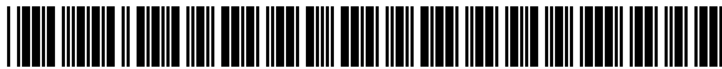

(19) **United States**

(12) **Patent Application Publication**

KIYOSE

(10) **Pub. No.: US 2015/0141827 A1**

(43) **Pub. Date: May 21, 2015**

(54) **ULTRASONIC DEVICE, METHOD FOR MANUFACTURING THE SAME, ELECTRONIC DEVICE AND ULTRASONIC IMAGING DEVICE**

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(21) Appl. No.: **14/541,528**

(22) Filed: **Nov. 14, 2014**

(30) **Foreign Application Priority Data**

Nov. 20, 2013 (JP) 2013-240276

Publication Classification

(51) **Int. Cl.**

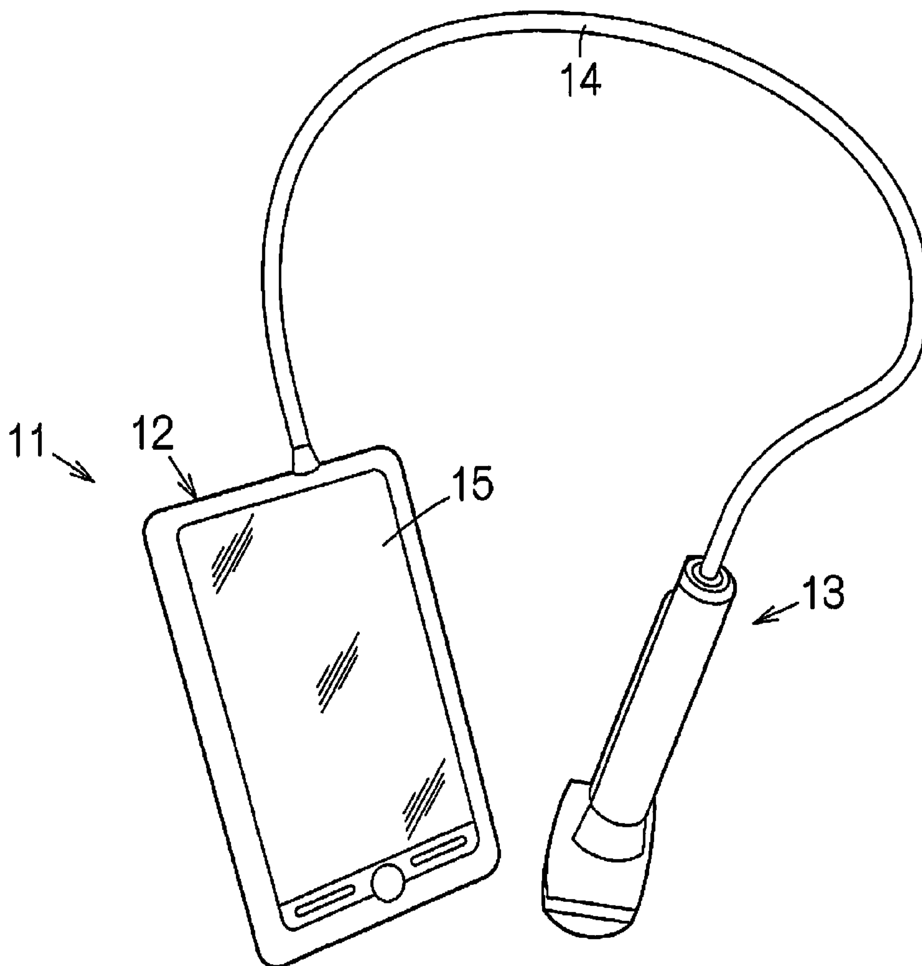
B06B 1/06	(2006.01)
H01L 41/33	(2006.01)
A61B 8/14	(2006.01)
A61B 8/00	(2006.01)
B06B 3/04	(2006.01)
H01L 41/053	(2006.01)

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

CPC ***B06B 1/0622*** (2013.01); ***B06B 3/04*** (2013.01); ***H01L 41/053*** (2013.01); ***A61B 8/14*** (2013.01); ***A61B 8/4488*** (2013.01); ***A61B 8/461*** (2013.01); ***H01L 41/33*** (2013.01)

(57) **ABSTRACT**

An ultrasonic device includes a substrate having a first opening, a second opening and a wall part partitioning the first opening and the second opening; a first vibration film and a second vibration film which close the first opening and the second opening respectively; a first piezoelectric element and a second piezoelectric element which are formed on surfaces of the first vibration film and the second vibration film opposite to the substrate; an acoustic matching layer which is disposed within the first opening and the second opening so as to come into contact with the first vibration film and the second vibration film.



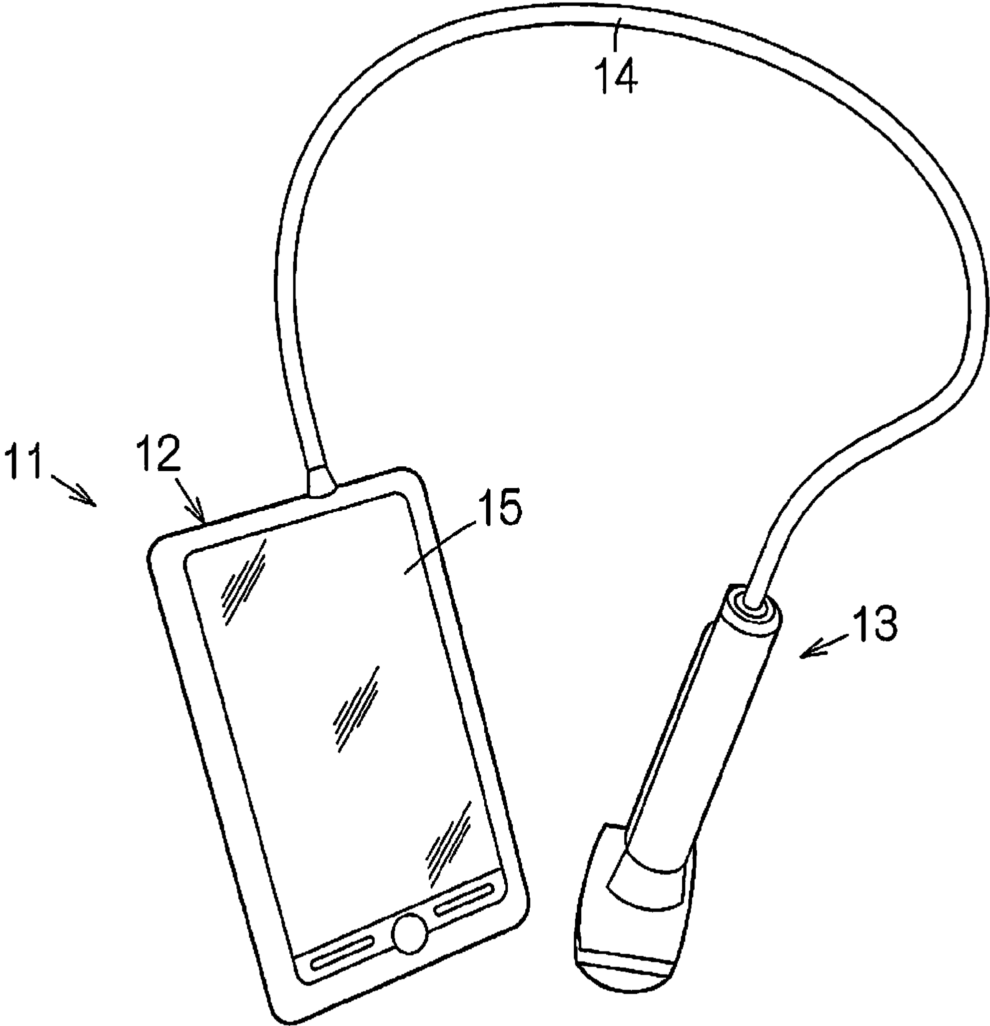


FIG. 1

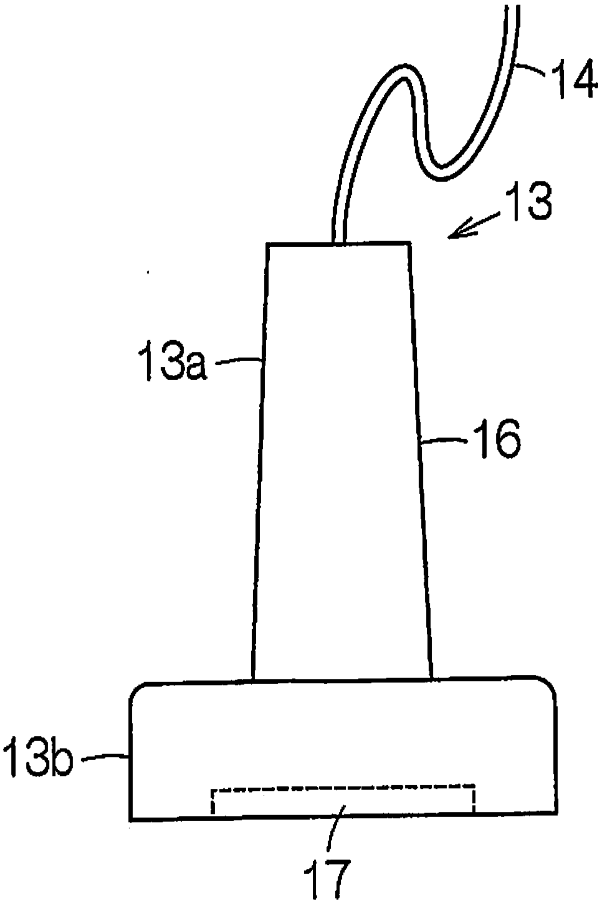


FIG. 2

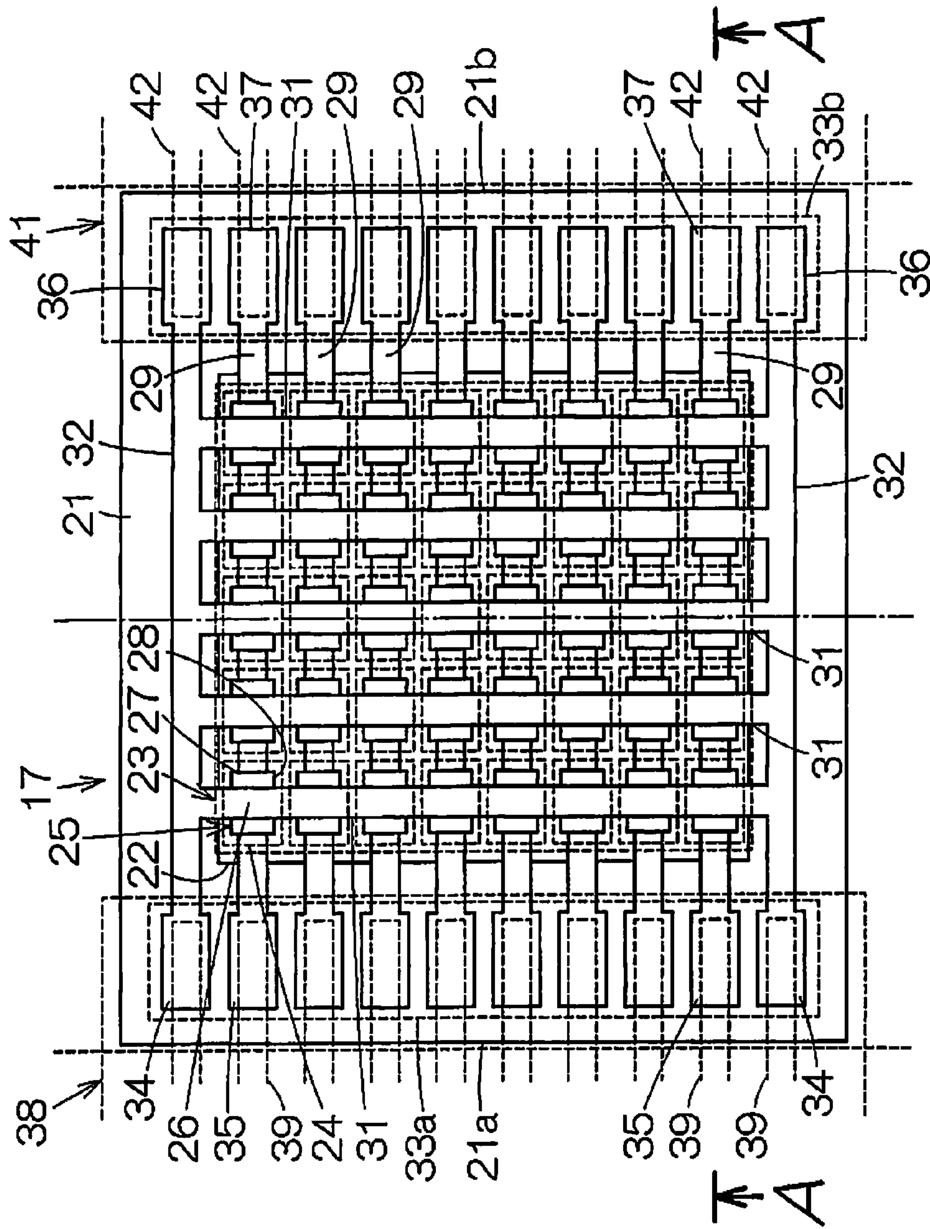


FIG. 3

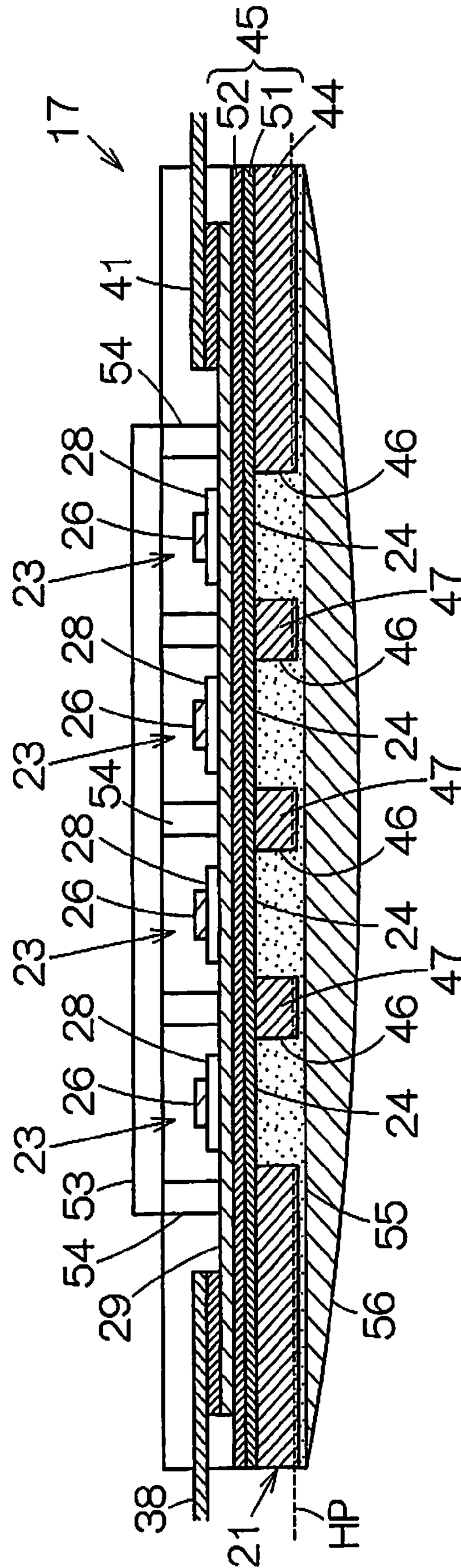


FIG. 4

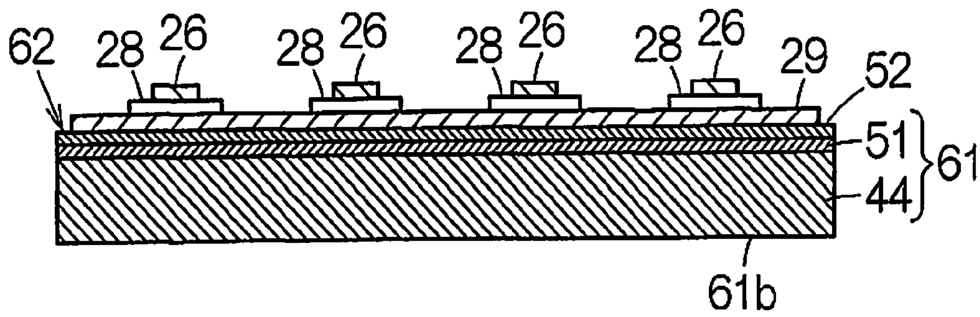


FIG. 5

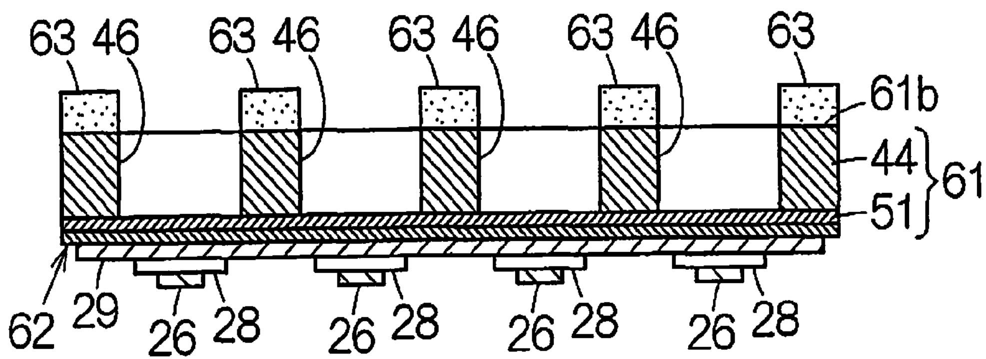


FIG. 6

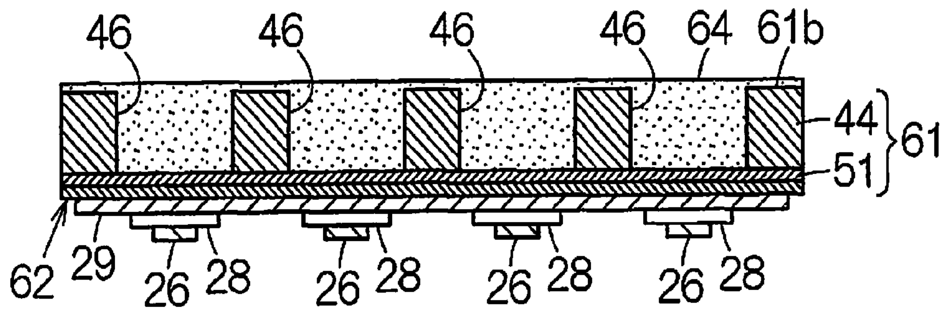


FIG. 7

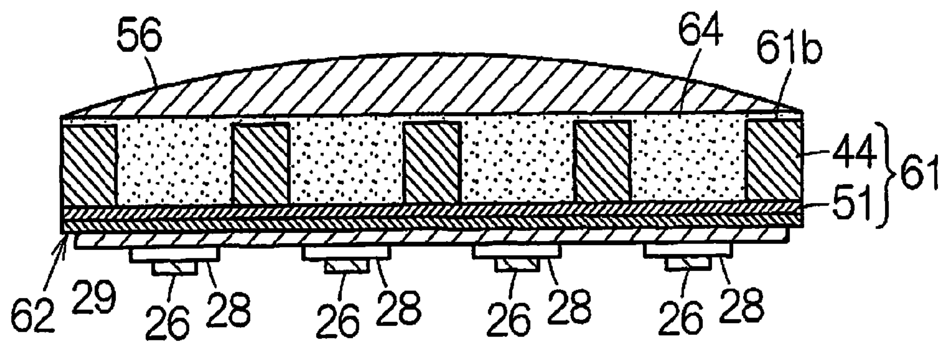


FIG. 8

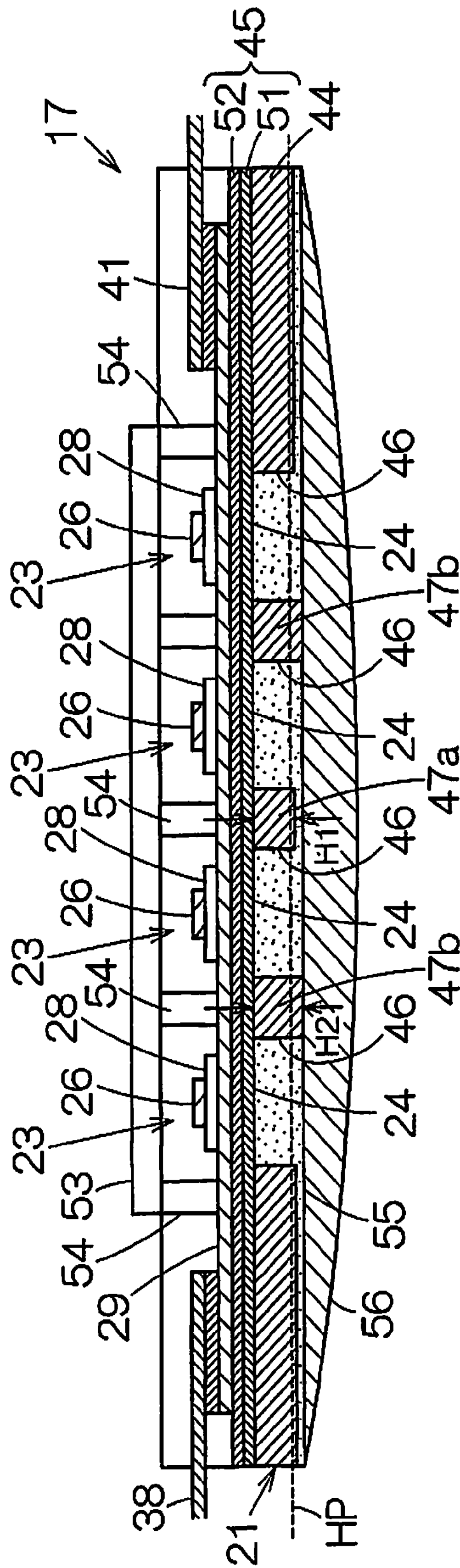


FIG. 9

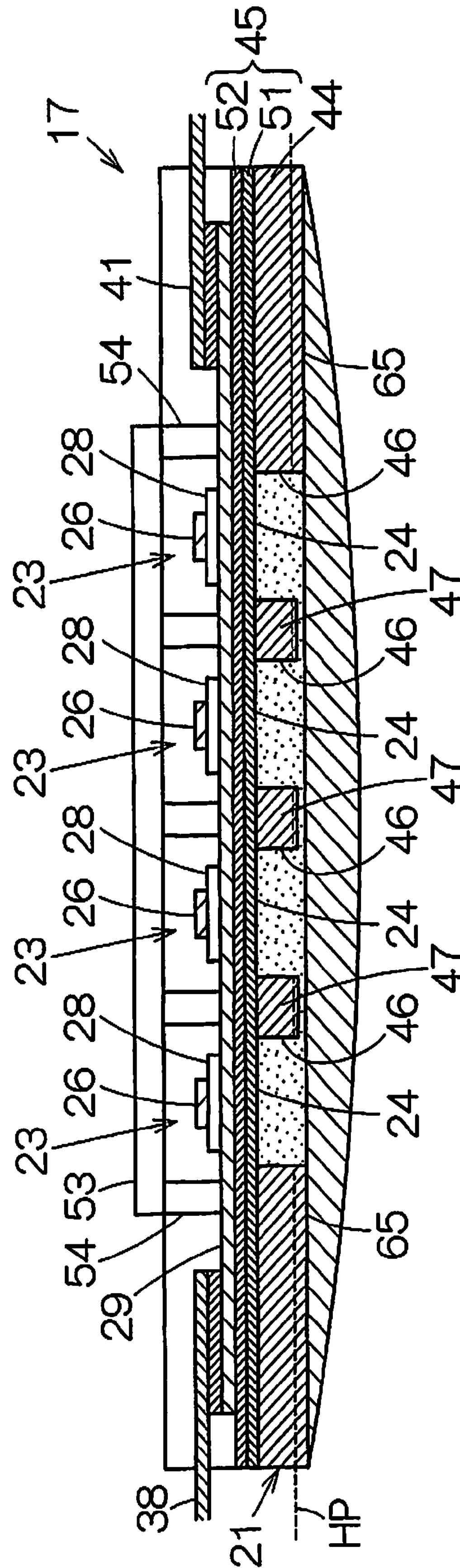


FIG.10

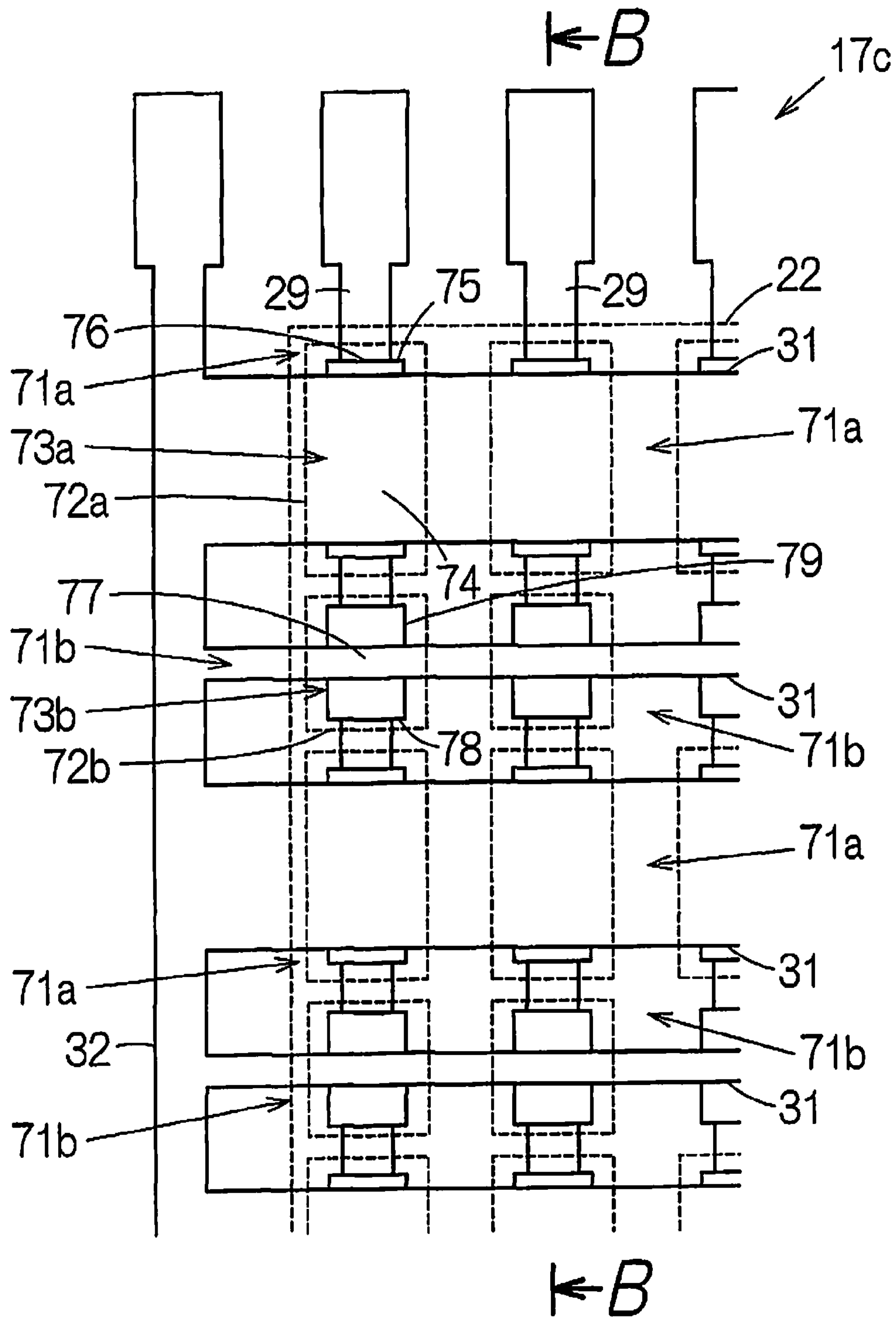


FIG.11

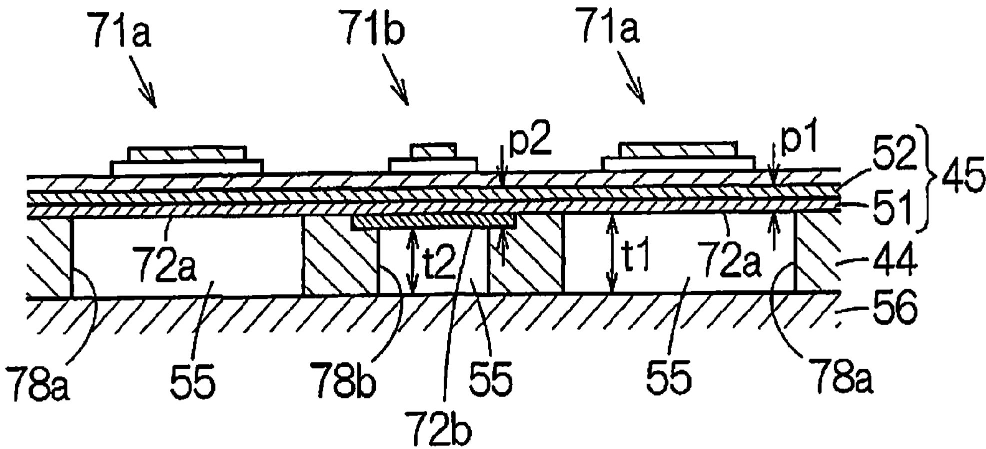


FIG.12

ULTRASONIC DEVICE, METHOD FOR MANUFACTURING THE SAME, ELECTRONIC DEVICE AND ULTRASONIC IMAGING DEVICE

BACKGROUND

[0001] 1. Technical Field

[0002] The present invention relates to an ultrasonic device and a manufacturing method thereof, as well as a probe, an electronic device and an ultrasonic imaging device which utilize the same.

[0003] 2. Related Art

[0004] An ultrasonic device utilizing a vibrating thin film is well known. For example, a piezoelectric element is formed on a surface of the vibration film of a silicon oxide or a silicon nitride, as described in JP-T-2010-539442. A structural body is disposed to surround the piezoelectric element on the surface of the vibration film. A rear surface of the vibration film is arranged to face a target object. As a result, an ultrasonic wave is transmitted from the rear surface of the vibration film.

[0005] JP-T-2010-539442 is an example of related art.

[0006] In JP-T-2010-539442, for formation of the piezoelectric element, the rear surface of the vibration film is supported on a surface of a substrate. Subsequent to the formation of the piezoelectric element, the substrate is removed by etching. The rear surface of the vibration film is formed to have a planar surface. When intervening between the vibration film and the target object, an acoustic matching layer and an acoustic coupling layer cause crosstalk between the vibration films adjacent to each other.

[0007] An ultrasonic device is desired that can effectively prevent crosstalk between vibration films arranged adjacent to each other.

SUMMARY

[0008] (1) An aspect of the invention refers to an ultrasonic device that is provided with a substrate, a first vibration film, a second vibration film, a first piezoelectric element, a second piezoelectric element, and an acoustic matching layer, wherein the substrate has a first opening, a second opening and a wall part partitioning the first opening and the second opening, wherein the first vibration film and the second vibration film respectively close the first opening and the second opening, wherein the first piezoelectric element and the second piezoelectric element are respectively formed on surfaces of the first vibration film and the second vibration film opposite to the substrate, and wherein the acoustic matching layer is disposed within the first opening and the second opening so as to be in contact with the first vibration film and the second vibration film.

[0009] The wall part partitions the acoustic matching layer. The acoustic matching layer adjacent to the first vibration film and the acoustic matching layer adjacent to the second vibration film are partitioned with the wall part. With this configuration, it is possible to prevent crosstalk of the ultrasonic wave propagated through the acoustic matching layer.

[0010] (2) A plurality of the first openings may be arranged in a row, and a plurality of the second openings may be arranged in a row parallel to the arrangement of the first openings. According this aspect, it is possible to connect the first piezoelectric elements arranged in a row commonly to electrodes in correspondence with the first openings arranged in a row. Similarly, it is possible to connect the second piezoelectric elements arranged in a row commonly to electrodes in correspondence with the second openings arranged in a row. In this configuration, it is possible to operate the arranged first piezoelectric elements simultaneously, and to operate the arranged second piezoelectric elements simultaneously. Thereby, it is possible to prevent crosstalk of the ultrasonic wave transmitting through the acoustic matching layer between the first piezoelectric element group and the second piezoelectric element group.

[0011] (3) The wall part may have a first wall part with a first height in a thickness direction of the substrate, and a second wall part with a second height larger than the first height. In this way, it is possible to provide the first wall part and the second wall part with individual functions.

[0012] (4) The ultrasonic wave device may be further provided with an acoustic lens which is in contact with the second wall part and coupled to the acoustic matching layer. According to this aspect, the acoustic matching layer is coupled to the acoustic lens for use of the ultrasonic device. The acoustic lens allows ultrasonic wave vibrations transmitted from the first vibration film and the second vibration film to converge at a focus position. The acoustic lens is positioned at the second wall part in relation to the first vibration film and the second vibration film. In this way, the thickness of the acoustic matching layer is determined by the distance between the acoustic lens and the first vibration film/the second vibration film. It is possible to control the thickness of the acoustic matching layer with the height of the second wall part. It is possible to set an optimum thickness for the transmission of ultrasonic wave. Besides, the acoustic matching layer can be prevented from deforming even when being pressed to an object to be detected, as much as possible. It is possible to maintain the acoustic matching layer.

[0013] (5) The acoustic matching layer may be disposed between the acoustic lens and the first wall part. According to this aspect, the acoustic matching layer contributes to an adhesion between the acoustic lens and the first wall part. Accordingly, it is possible to suppress the decrease in an adhesion area between the acoustic matching layer and the acoustic lens, regardless of the disposition of the wall part, as much as possible. It is possible to stabilize the connection between the acoustic lens and the acoustic matching layer.

[0014] (6) The ultrasonic device may be provided with an exterior frame which surrounds the first opening and the second opening consecutively in a plan view viewed from the thickness direction of the substrate and has a height larger than the wall part in relation to the thickness direction of the substrate. According to this aspect, it is possible to inject a raw material of the acoustic matching layer as a fluid into the first opening and the second opening for the formation of the acoustic matching layer. Besides, the exterior frame can block the raw material flowing from the first opening and the second opening. In this configuration, it is possible to securely inject the raw material into all of the first openings and the second openings.

[0015] (7) The first vibration film may have a first resonance frequency, and the second vibration film may have a second resonance frequency different from the first resonance frequency. The vibration film exhibits the maximum sensitivity for the ultrasonic wave in a band region of the resonance frequency. Accordingly, it is possible to receive the ultrasonic wave in band regions varying depending on the vibration films. In this configuration, it is possible to detect a harmonic

component of the transmitting frequency, or expand the received band region of the ultrasonic wave.

[0016] (8) The acoustic matching layer may have the same thickness at the first opening and the second opening. Ordinarily, the thickness of the acoustic matching layer corresponds to an odd multiple of a quarter of a wavelength of ultrasonic wave. Accordingly, it is possible to achieve acoustic matching even when the same thickness is set at the first opening and the second opening in case a harmonic relationship is satisfied between the first resonance frequency and the second resonance frequency.

[0017] (9) The acoustic matching layer may have different thicknesses at the first opening and the second opening. Ordinarily, the thickness of the acoustic matching layer corresponds to an odd multiple of a quarter of a wavelength of ultrasonic wave. The thickness of the acoustic matching layer can be optimized for each of the first openings and the second openings.

[0018] (10) The ultrasonic device can be assembled into a probe to be utilized. In this instance, the probe can be provided with the ultrasonic device and a housing supporting the ultrasonic device.

[0019] (11) The ultrasonic device can be assembled into an electronic device to be utilized. In this instance, the electronic device is connected to the ultrasonic device and a processing device which is connected to the ultrasonic device and processes the output of the ultrasonic device.

[0020] (12) The ultrasonic device can be assembled into an ultrasonic imaging device to be utilized. In this instance, the ultrasonic device can be provided with the ultrasonic device and a display device for displaying an image created from the output of the ultrasonic device.

[0021] (13) Another aspect of the invention refers to a method for manufacturing an ultrasonic device, which includes forming a first piezoelectric element and a second piezoelectric element on a surface of a film material of a substrate which has the film material on a first surface; forming a first opening and a second opening which are mutually partitioned with a wall part from a second surface on a rear side with respect to the first surface of the substrate, and forming a first vibration film supporting the first piezoelectric element and a second vibration film supporting the second piezoelectric element on the film material; injecting a fluid raw material of an acoustic matching layer into the first opening and the second opening; and covering the injected fluid with an acoustic lens and curing the fluid body to attach the acoustic lens.

[0022] In the manufactured ultrasonic device, the wall part partitions the acoustic matching layer. The acoustic matching layer in contact with the first vibration film and the acoustic matching layer in contact with the second vibration film are separated from each other with the wall part. In this way, it is possible to prevent crosstalk of the ultrasonic wave transmitting through the acoustic matching layer. For the formation of the acoustic matching layer, the fluid of the raw material can be simply injected within the first opening and the second opening, making it possible to simplify the manufacturing process. The acoustic matching layer can be securely adhered to the first vibration film, the second vibration film and the acoustic lens.

[0023] (14) The wall part may have a first wall part with a first height in a thickness direction of the substrate and a second wall part with a second height larger than the first height. According to this aspect, the acoustic lens comes into contact with the second wall part. The acoustic lens is positioned at the second wall part in relation to the first vibration film and the second vibration film. In this instance, the acoustic matching layer can be intervened between the acoustic lens and the first wall part. The acoustic matching layer can contributes to the adhesion between the acoustic lens and the first wall part.

[0024] (15) For the formation of the first opening and the second opening, the film material can be formed at the planar surface with the first vibration film having a first film thickness and the second vibration film having a second film thickness. According to this aspect, the injected fluid is allowed to extend so as to be planar surface. Accordingly, the fluid has different thicknesses at a part corresponding to the first vibration film and a part corresponding to the second vibration film. In this way, it is possible to control the thickness of the acoustic matching layer.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] The invention will be described with reference to the accompanying drawings, wherein like numbers reference like elements.

[0026] FIG. **1** is an external view schematically showing one specific example of an electronic device, namely an ultrasonic diagnosis device.

[0027] FIG. **2** is an expanded front view of an ultrasonic probe.

[0028] FIG. **3** is an expanded plan view of an ultrasonic device according to the first embodiment.

[0029] FIG. **4** is a cross-sectional view along A-A line in FIG. **3**.

[0030] FIG. **5** is an expanded cross-sectional view schematically showing how a piezoelectric element is formed in a method for manufacturing an ultrasonic device.

[0031] FIG. **6** is an expanded cross-sectional view schematically showing a step of forming an opening in the method for manufacturing the ultrasonic device.

[0032] FIG. **7** is an expanded cross-sectional view schematically showing a step of injecting a material of an acoustic matching layer in the method for manufacturing the ultrasonic device.

[0033] FIG. **8** is an expanded cross-sectional view schematically showing a step of adhering an acoustic lens in the method for manufacturing the ultrasonic device.

[0034] FIG. **9** is an expanded cross-sectional view corresponding to FIG. **4** according to a second embodiment of the ultrasonic device.

[0035] FIG. **10** is an expanded cross-sectional view corresponding to FIG. **4** according to a third embodiment of the ultrasonic device.

[0036] FIG. **11** is an expanded partial plan view according to a fourth embodiment of the ultrasonic device.

[0037] FIG. **12** is a partial cross-sectional view along B-B line in FIG. **11**.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0038] The following describes an embodiment of the invention with reference to the attached drawings. The embodiments explained below are not intended to limit improperly the contents of the invention described in claims. None of the structural details explained in the embodiments are absolutely necessary for the solution of the invention.

[0039] (1) Overall Structure of an Ultrasonic Diagnosis Device

[0040] FIG. **1** schematically shows one specific example of an electronic device, namely an ultrasonic diagnosis device (ultrasonic imaging device) **11**. The ultrasonic diagnosis device **11** is provided with a device terminal (processing device) **12** and an ultrasonic probe (probe) **13**. The device terminal **12** and the ultrasonic probe **13** are connected to each other via a cable **14**. Electric signals are transmitted through the cable **14** between the device terminal **12** and the ultrasonic probe **13**. A display panel (display device) **15** is assembled into the device terminal **12**. A screen of the display panel **15** is exposed at a surface of the device terminal **12**. In the device terminal **12**, an image is created on the basis of ultrasonic waves detected with the ultrasonic probe **13**. An imaged detection result is displayed on the screen of the display panel **15**.

[0041] As shown in FIG. **2**, the ultrasonic probe **13** has a housing **16**. An ultrasonic device **17** is accommodated within the housing **16**. A surface of the ultrasonic device **17** can be exposed at a surface of the housing **16**. The ultrasonic device **17** outputs the ultrasonic wave from the surface and receives a reflection wave of the ultrasonic wave. Moreover, the ultrasonic wave **13** can be provided with a probe head **13***b* detachably connected to a probe main body **13***a*. In this case, the ultrasonic device **17** can be assembled within the housing **16** of the probe head **13***b*.

[0042] (2) Configuration of the Ultrasonic Device According to First Embodiment

[0043] FIG. **3** schematically shows a plan view of the ultrasonic device **17** according to the first embodiment. The ultrasonic device **17** is provided with a base **21**. An element array **22** is provided on the base **21**. The array **22** is constituted by an arrangement of ultrasound transducer elements (hereinafter referred to as “elements”) **23**. The arrangement is in form of a matrix (an array) with a plurality of lines and a plurality of rows. The arrangement may also be established as a zigzag arrangement. In such a zigzag arrangement, a group of elements **23** in an even row can be displaced with respect to a group of elements **23** in an odd row by one half of a line pitch. One of the number of the elements in an odd row and the number of the elements in an even row may be lower than the other by one.

[0044] Each element **23** is provided with a vibration film **24**. The vibration films **24** will be explained below in detail. In FIG. **3**, the contour of each vibration film **24** is depicted as a dotted line in a plan view in a direction perpendicular to a film surface of the vibration film **24** (a plan view in a thickness direction of a substrate). A piezoelectric element **25** is formed on the vibration film **24**. In the piezoelectric element **25**, a piezoelectric film **28** is interposed between a top electrode **26** and a bottom electrode **27**, as described below. These are layered one above the other. The supersonic device **17** is formed as a single ultrasonic transducer element chip.

[0045] A plurality of first electric conductors **29** is formed on the surface of the base **21**. The first electric conductors **29** extend in parallel to each other in a row direction of the arrangement. One first electric conductor **29** is assigned to each row of elements **23**. One first electric conductor **29** is disposed commonly to (i.e. shared by) the elements **23** arranged in a row direction of the arrangement. The first electric conductor **29** forms the bottom electrode **27** for each of the elements **23**. For example, a laminate of titanium (Ti), iridium (Ir), platinum (Pt) and titanium (Ti) can be utilized for the first electric conductor **29**. It is also possible to use another electric conductor as the first electric conductor **29**.

[0046] A plurality of second electric conductors **31** is formed on the surface of the base **21**. The second electric conductors **31** extend in parallel to each other in a row direction of the arrangement. One second electric conductor **31** is assigned to each line of the elements **23**. One second electric conductor **31** is disposed commonly to the elements **23** arranged in the line direction of the arrangement. The second electric conductor **31** forms the top electrode **26** for each element **23**. The second electric conductors **31** are connected at both ends to a pair of extension wires **32**. The extension wires **32** extend in parallel to each other in the row direction of the arrangement. Accordingly, all of the second electric conductors **31** have the same length. In this configuration, the top electrodes **26** are connected commonly to the elements **23** of the overall matrix. The second electric conductor **31** can be made of iridium (Ir), for example. It is also possible to use another electric conductor as the second electric conductor **31**.

[0047] It is possible to switch the electrical connection of the elements **23** for each row. In response to the switch of the electrical connection, it is possible to achieve a linear scan and a sector scan. Since the elements **23** in a single row can output ultrasonic waves simultaneously, the number of single lines, that is, the number of lines of the arrangement can be set depending on the output level of the ultrasonic wave. The number of lines can be set in a range of 10 to 15, for example. In figure, some lines are not shown, and five lines are shown. The number of rows of the arrangement can be set depending on the extent of a scan range. The number of rows can be set to 128 or 256, for example. In the figures, some rows are not shown, and only eight rows are shown. The functions of the top electrode **26** and the bottom electrode **27** can be reversed. That is, the bottom electrodes can be connected commonly to the elements **23** of overall matrix, while the top electrodes can be connected commonly to each row of the arrangement.

[0048] The contour of the base **21** has a first side **21***a* and a second side **21***b*, which are defined by a pair of mutually parallel lines and face each other. A first terminal array **33***a* is disposed as a single line between the first side **21***a* and a contour of the element array **22**. A line of a second terminal array **33***b* is disposed as a single line between the second side **21***b* and a contour of the element array **22**. The first terminal array **33***a* can form one line parallel to the first side **21***a*. The second terminal array **33***b* can form one line parallel to the second side **21***b*. The first terminal array **33***a* is constituted by a pair of top electrode terminals **34** and a plurality of bottom electrode terminals **35**. Similarly, the second terminal array **33***b* is constituted by a pair of top electrode terminals **36** and a plurality of bottom terminals **37**. The two ends of each one extension wire **32** are respectively connected to the top electrode terminals **34**, **36**. The extension wire **32** and the top electrodes **34**, **36** can be formed plane-symmetrically in relation to a perpendicular plane bisecting the element array **22**. The two ends of one second electric conductor **31** are respectively connected to the bottom electrode terminals **35**, **37**. The second electric conductor **31** and the bottom electrodes **35**, **37** can be formed plane-symmetrically in relation to a perpendicular plane bisecting the element array **22**. Herein, the contour of the base **21** has a rectangular shape. The contour of the base **21** may also be square or trapezoidal.

[0049] A first flexible printed circuit board (hereinafter referred to as “first circuit board”) **38** is connected to the base

21. The first circuit board **38** covers the first terminal array **33***a*. The first circuit board **38** is provided at its one end with electrically conductive lines, namely first signal lines **39** that respectively correspond to the top electrode terminals **34** and the bottom electrode terminals **35**. The first signal lines **39** are respectively connected so as to face the top electrode terminals **34** and the bottom electrode terminals **35**. Similarly, a second flexible printed circuit board (hereinafter referred to as "second circuit board") **41** covers the base **21**. The second circuit board **41** covers the second terminal array **33***b*. The second circuit board **41** is provided at its one end with electrically conductive lines, namely second signal lines **42** that respectively correspond to the top electrode terminals **36** and the bottom electrode terminals **37**. The second signal lines **42** are respectively connected so as to face the top electrode terminals **36** and the bottom electrode terminals **37**.

[0050] As shown in FIG. **4**, the base **21** is provided with a base plate **44** and a flexible film **45**. The flexible film **45** is formed over the entire surface of the base plate **44**. The base plate **44** is made of silicon (Si), for example. The base plate **44** is provided with an opening **46** for each element **23**. The openings **46** are disposed in array form in relation to the base plate **44**. A contour of a region in which the openings **46** are disposed corresponds to a contour of the element array **22**. A partitioning wall **47** is disposed between two openings adjacent to each other. A wall thickness of the partitioning wall **47** corresponds to an interval between the openings **46**. The partitioning wall **47** defines two wall surfaces within planes which extend in parallel to each other. The wall thickness corresponds to a distance between the two wall surfaces. That is, the wall thickness can be defined by a length of a normal line which is orthogonal to the wall surfaces and interposed between the wall surfaces.

[0051] The flexible film **45** is made of a silicon oxide (SiO_2) layer **51** layered on a surface of the base plate **44** and a zirconium oxide (ZrO_2) layer **52** layered on a surface of the silicon oxide layer **51**. The flexible film **45** closes the openings **46**. In this configuration, a portion of the flexible film **45** forms the vibration film **24**, corresponding to the contour of the opening **46**. The vibration film **24** is that portion of the flexible film **45** that is exposed through the opening **46**, and that is capable of vibrating in the thickness direction of the base plate **44**. The film thickness of the silicon oxide **51** can be set in accordance with the resonance frequency.

[0052] The first electric conductor **29**, the piezoelectric film **28** and the second electric conductor **31** are layered in this order on a surface of the vibration film **24**. The piezoelectric film **28** can be made of lead zirconate titanate (PZT), for example. It is also possible to use another piezoelectric material as the piezoelectric film **28**. The piezoelectric film **28** covers at least a portion of the bottom electrode **27** and a portion of the vibration film **24**. The top electrode **26** covers at least a portion of the piezoelectric film **28**. Herein, the piezoelectric film **28** covers the surface of the first electric conductor **29** completely under the second electric conductor **31**. With the function of the piezoelectric film **28**, it is possible to prevent short-circuits between the first electric conductor **29** and the second electric conductor **31**.

[0053] A backing material **53** is attached on the flexible film **45** on a surface of the base plate **44**. The backing material **53** forms voids between the backing material **53** and the surface of the flexible film **45**. The piezoelectric elements **25** are disposed within these voids. The backing material **53** is supported on a surface of the flexible film **45** by a wall material **54**. The wall material **54** maintains an interval between the backing material **53** and the surface of the flexible film **45**. The wall material **54** is supported with the base material **44** on an exterior side of a contour of the openings **46**.

[0054] An acoustic matching layer **55** is layered on a rear surface on a rear side of the surface of the base plate **44**. The acoustic matching layer **55** covers the rear surface of the base plate **44** while also being disposed within the openings **46**. The acoustic matching layer **55** comes into contact with the vibration film **24** within the openings **46**. The acoustic matching layer **55** is adhered intimately to the vibration film **24** without forming any voids. For example, a silicone resin film can be used for the acoustic matching layer **55**. The partitioning walls **47** have a larger acoustic impedance than the acoustic matching layer **55**.

[0055] An acoustic lens **56** is layered on the acoustic matching layer **55**. The acoustic lens **56** is adhered intimately to a surface of the acoustic matching layer **55** without forming any voids. The exterior surface of the acoustic lens is formed into a partially cylindrical surface. The partially cylindrical surface has an apex line that is parallel to the second electric conductors **31**. A curvature of the partially cylindrical surface is set in accordance with a focus position of the ultrasonic wave transmitted from the row of elements **23** connected to one of the second electric conductors **31**. The acoustic lens **56** can be made of a silicone resin, for example.

[0056] (2) Operation of the Ultrasonic Diagnosis Device

[0057] Next, the operation of the ultrasonic diagnosis device will be briefly explained. For the transmission of ultrasonic waves, a pulse signal is supplied to the piezoelectric elements **25**. The pulse signal is supplied to the elements **23** in each row through the bottom electrode terminals **35**, **37** and the top electrode terminals **34**, **36**. An electric field acts on the piezoelectric film **28** between the bottom electrode **27** and the top electrode **26** at each element **23**. The piezoelectric film **28** vibrates in response to the ultrasonic wave. The vibration of the piezoelectric film **28** is transmitted to the vibration film **24**. In this way, the vibration film **24** performs ultrasonic vibration. The ultrasonic vibration of the vibration film **24** is transmitted within the acoustic matching layer **55**. The ultrasonic vibration is transmitted to the acoustic lens **56** to be emitted therefrom. As a result, a desired ultrasonic beam is transmitted towards on object (for example, the interior of a human body).

[0058] The reflection wave of the ultrasonic wave is transmitted to the acoustic lens **56** and the acoustic matching layer **55** so as to vibrate the vibration film **24**. The ultrasonic vibration of the vibration film **24** allows the piezoelectric film **28** to perform ultrasonic vibration at the desired frequency. An electric voltage is output from the piezoelectric elements **25** in response to piezoelectric effect of the piezoelectric elements **25**. An electric potential is generated between the top electrode **26** and the bottom electrode **27** at each element **23**. The electric potential is output as an electric signal from the bottom electrode terminals **35**, **37** and the top electrode terminals **34**, **36**, enabling the detection of the ultrasonic wave.

[0059] The ultrasonic wave is repetitively transmitted and received. As a result, a linear scan and a sector scan are achieved. After completion of the scan, an image is created on the basis of a digital output signal. The created image is displayed on a screen of the display panel **15**.

[0060] Ordinarily, the ultrasonic probe **13** is pressed to an object to be detected for the formation of the ultrasonic image. In this way, a fluid acoustic coupling material inter-

venes between the object to be detected and the acoustic lens **56**. For example, water can be utilized for the acoustic coupling material. The function of the acoustic coupling material assures an acoustic matching between the object to be detected and the acoustic lens **56**, making it possible to prevent an ultrasonic reflection at an interface. The wire pattern and so on, such as the piezoelectric elements **25**, the first electric conductors **29** and the second electric conductors **31** are disposed on a front side of the base **21**, allowing the piezoelectric elements **25** and the wire pattern to be separated by the flexible film **45** from the acoustic coupling material. With this configuration, it is possible to protect the piezoelectric elements **25** and the wire pattern from water. Accordingly, a moisture-proof material should be used for the flexible film **45**.

[0061] For the ultrasonic wave transmission, the vibration film **24** performs ultrasonic vibration. The ultrasonic vibration is transmitted within the acoustic matching layer **55** so as to be transmitted from the interface of the acoustic matching layer **55**. The ultrasonic vibration is transmitted to the acoustic lens **56** through the interface. In this configuration, the acoustic matching layer **55** is partitioned with the partitioning walls **47** arranged between adjacent vibration films **24**. The acoustic matching layer **55**, which is in contact with each vibration film **24**, is divided with the partitioning walls **47**. Interfaces are generated acoustically between adjacent acoustic matching layers **55**, due to the difference in the acoustic impedance between the acoustic matching layers **55** and the partitioning walls **47**. The interfaces prevent ultrasonic transmission. The ultrasonic crosstalk is prevented during the ultrasonic vibration of a single vibration film **24**. If the partitioning walls **47** were not formed and the acoustic matching layer **55** were to extend commonly for all the elements **23**, then the ultrasonic vibration transmitted from one element **23** would be reflected from the interface between the acoustic matching layer **55** and the acoustic lens **56**, and propagated to the vibration films **24** of other elements **23**.

[0062] In the ultrasonic device **17**, a group of elements **23** in one row is connected commonly to the same first electric conductor **29**. The electrodes can be connected commonly to the piezoelectric elements **25** in one row, in correspondence with the openings **46**. The rows of the openings **46** are arranged in parallel. The piezoelectric elements **25** of each row can operate simultaneously. The partitioning walls **47** are formed at least between adjacent openings **46** of different rows, making it possible to prevent crosstalk of the ultrasonic wave propagated through the acoustic matching layer **55** between a group of the piezoelectric elements **25** in one row and a group of the piezoelectric elements **25** in an adjacent row.

[0063] (3) Method for Manufacturing the Ultrasonic Device

[0064] Next, a method for manufacturing the ultrasonic device **17** will be briefly explained. As shown in FIG. **5**, a substrate **61** is prepared. The substrate **61** is made of silicon, for example. The surface of the substrate **61** is subjected to thermal treatment to be provided with an oxide film. Silicon of the substrate **61** is oxidized to be formed into silicon oxide. The oxide film has a uniform film thickness. In this way, the substrate **44** and the silicon oxide layer **51** are formed from the substrate **61**. A zirconium layer **52** is formed over the entire surface of the silicon oxide layer **51**, and can be formed by sputtering, for example. The zirconium film is formed to have a uniform film thickness. The zirconium film is subjected to oxidization treatment. In this way, the zirconium oxide layer **52** is formed to have a uniform film thickness. The laminate of the silicon oxide layer **51** and the zirconium oxide layer **52** establishes a film material **62**. The film material **62** corresponds to the flexible film **45**.

[0065] Subsequently, the piezoelectric elements **25** are formed on the surface of the film material **62**. For example, a raw material layer of an electrically conductive material is formed over the entire surface of the zirconium oxide layer **52**, and can be formed by sputtering, for example. The raw material layer is formed to have a uniform film thickness. A pattern of photoresist is formed on the surface of the raw material layer. The pattern is formed into the shape of the first electric conductor **29**. Etching treatment is performed from the surface of the raw material layer. As a result, the first electric conductor **29** is formed from the raw material layer. Similarly, the piezoelectric film **28** and the top electrode **26** (second electric conductor **31**) are formed on the surface of the film material **62**.

[0066] In this way, after the first electric conductor **29**, the second electric conductor **31**, the top electrode terminals **34**, **36** and the bottom electrode terminals **35**, **37** are formed in addition to the piezoelectric elements **25**, as shown in FIG. **6**, the openings **46** are formed in the substrate **44** from the rear surface (second surface) of the substrate **61**. For the formation, the substrate **44** is subjected to etching treatment from the rear side. A pattern of the photoresist **63** is formed on the rear surface **61***b* of the substrate **61**. The pattern is shaped into the contour of the openings **46**. With the etching treatment, the rear surface **61***b* of the substrate **61** is etched away at the locations outside the photoresist **63**. In this way, the silicon oxide layer **51** acts as an etching stop layer. As a result, the film material **62** establishes the vibration film **24** at the opening **46**.

[0067] Subsequently, as shown in FIG. **7**, a fluid raw material **64** of the acoustic matching layer **55** is injected into the openings **46**. The raw material **64** has fluidity, and fills the voids within the openings **46**. The raw material **64** comes into complete contact with the vibration film **24** sufficiently. In this situation, the fluid raw material **64** extends evenly on the rear surface **61***b* of the substrate **61**. A planar surface of the raw material **64** extends in a single plane at the rear surface **61***b* of the substrate **61**.

[0068] As shown in FIG. **8**, the injected fluid raw material **64** is covered with the acoustic lens **56**. The raw material **64** has fluidity and comes into complete contact with the acoustic lens **56**. Subsequently, the fluid is cured. With the curing of the fluid, the acoustic matching layer **55** is established. The acoustic lens **56** adheres to the acoustic matching layer **55**. The acoustic matching layer **55** is securely adhered intimately to the vibration film **24** and the lens **56**. According to the adhesion, secure ultrasonic transmission is established.

[0069] Subsequently, the first circuit board **38** and the second circuit board **41** are connected to the substrate **44**. After the first circuit board **38** and the second circuit board **41** are mounted, a backing material **53** is connected to the surface of the substrate **61**. In this way, the ultrasonic device **17** is manufactured.

[0070] (4) Configuration of Ultrasonic Device According to Second Embodiment

[0071] FIG. **9** schematically shows a cross-sectional view of the ultrasonic device **17***a* according to the second embodiment. In the ultrasonic device **17***a*, the partitioning walls **47** include a first wall **47***a* with a first height H1 in a thickness

direction of the substrate **47** and a second wall **47*b*** with a second height H2. The second height H2 is larger than the first height H1. The first height H1 and the second height H2 can be measured from the rear surface of the silicon oxide layer **51** in a direction that is orthogonal to the surface of the flexible film **45**. Herein, the first height H1 and the second height H2 correspond to the thickness of the substrate **44**. The acoustic lens **56** comes into contact with a top surface of the second wall **47*b***. The acoustic matching layer **55** is disposed between the acoustic lens **56** and the first wall **47*a***. With respect to other aspects, the ultrasonic device **17*a*** has the same configuration as that according to the first embodiment.

[0072] In the ultrasonic device **17*a***, the acoustic lens **56** is positioned at the second wall **47*b*** in relation to the vibration film **24**. In this way, the thickness of the acoustic matching layer **55** is set by the distance between the acoustic lens **56** and the vibration film **24**. The thickness of the acoustic matching layer **55** can be controlled by the height of the second wall **47*b***. The optimum thickness for ultrasonic transmission can thus be set. Besides, even when the acoustic lens **56** is pressed to the object to be detected, the acoustic matching layer **55** can be kept from deforming as much as possible. The thickness of the acoustic matching layer **55** can be maintained.

[0073] As mentioned above, the acoustic matching layer **55** functions as an adhesive for the acoustic lens **56**. The acoustic matching layer **55** is interposed between the first wall **47*a*** and the acoustic lens **56**, thereby contributing to adhesion of the acoustic lens **56** and the first wall **47*a***. Regardless of the position of the partitioning walls **47**, it is possible to restrict the reduction of the adhesion area between the acoustic matching layer **55** and the acoustic lens **56** to a minimum. It is possible to stabilize the coupling of the acoustic lens **56** to the acoustic matching layer **55**.

[0074] For fabrication of the ultrasonic device **17*a***, the rear surface **61*b*** of the substrate **61** is subjected to etching treatment in the formation of the openings **46**. In this way, when the etching treatment can be suppressed at a portion corresponding to the second wall **47*b***, it is possible to establish the second height H2 of the second wall **47*b***. When being adhered, the acoustic lens **56** is pressed to the top surface of the second wall **47*b***. The second wall **47*b*** positions the acoustic lens **56**.

[0075] (5) Configuration of Ultrasonic Device According to Third Embodiment

[0076] FIG. **10** schematically shows a cross-sectional view of the ultrasonic device **17*b*** according to the third embodiment. In the ultrasonic device **17*b***, an external frame is formed at a rear surface of the substrate **44** so as to consecutively surround all of the openings **46**. The external frame has a larger height than the partitioning walls **47**. The acoustic lens **56** is received at the external wall. Therefore, the external frame positions the acoustic lens **56**. The acoustic matching layer **55** is disposed at an interior side of the external frame. The acoustic matching layer **55** fills the openings **46**. The acoustic matching layer **55** contributes to the adhesion between the acoustic lens **56** and the partitioning walls **47**. Regardless of the position of the partitioning walls **47**, it is possible to restrict the reduction of the adhesion area between the acoustic matching layer **55** and the acoustic lens **56** to a minimum. It is possible to stabilize the coupling of the acoustic lens **56** to the acoustic matching layer **55**.

[0077] For fabrication of the ultrasonic device **17*b***, the rear surface **61*b*** of the substrate **61** is subjected to etching treatment in the formation of the openings **46**. At this time, it is possible to establish the height of the external frame **65** by restricting the etching at the locations corresponding to the external frame **65**. For the adhesion of the acoustic lens **56**, the raw material of the acoustic matching layer **55** is injected as a fluid into the openings **46**. The external frame **65** blocks the raw material flowing from the opening **46**. In this way, the raw material can be securely injected within all of the openings **46**. The acoustic lens **56** is pressed to the external frame **65**. The external frame **65** positions the acoustic lens **56**.

[0078] (6) Configuration of Ultrasonic Device According to Fourth Embodiment

[0079] FIG. **11** schematically shows an expanded partial plan view of the ultrasonic device **17*c*** according to the fourth embodiment. The element array **22** of the ultrasonic device **17*c*** is constituted by an arrangement of first ultrasonic transducer elements (which are referred to as "first elements", hereinafter) **71*a*** and second ultrasonic transducer elements (which are referred to as "second elements", hereinafter) **71*b***. Herein, the first elements **71*a*** and the second elements **71*b*** are alternately disposed in a row direction. However, the arrangement of the first elements **71*a*** and the second elements **71*b*** is not limited to this arrangement.

[0080] The first elements **71*a*** are provided with a first vibration film **72*a***. The second elements **71*b*** are provided with a second vibration film **72*b***. In FIG. **11**, contours of the first vibration films **72*a*** and the second vibration films **72*b*** are shown as dotted lines in a plan view in a direction orthogonal to film surfaces of the first vibration film **72*a*** and the second vibration film **72*b*** (plan view in thickness direction of the substrate). A first piezoelectric element **73*a*** is formed on the first vibration film **72*a***. A second piezoelectric element **73*b*** is formed on the second vibration film **72*b***. In the first piezoelectric element **73*a***, a piezoelectric film **76** is interposed between a top electrode **74** and a bottom electrode **75**. These are layered in this order. Similarly, in the second piezoelectric element **73*b***, a piezoelectric film **79** is interposed between a top electrode **76** and a bottom electrode **77**. These are layered in this order. The first electric conductor **29** is connected commonly to the bottom electrodes **75**, **78** of the first elements **71*a*** and the second elements **71*b*** of a single row. The second electric conductor **31** is connected commonly to the top electrodes **74**, **77** of the first elements **71*a*** or the second elements **71*b*** of a single row. Herein, the first vibration film **72*a*** has an area different from that of the second film **72*b***. The dimensions of the first vibration film **72*a*** depend on the first resonance frequency. The dimensions of the second vibration film **72*b*** depend on the second resonance frequency. The second resonance frequency corresponds to a harmonic wave of the first resonance frequency. However, other combinations of frequencies can be employed.

[0081] As shown in FIG. **12**, the substrate **44** is provided with first openings **78*a*** corresponding to the individual first elements **71*a***. The substrate **44** is provided with the second openings **78*b*** corresponding to the individual second elements **71*b***. The acoustic matching layer **55** has a first thickness t1 at the first openings **78*a***. The acoustic matching layer **55** has a second thickness t2 at the second openings **78*b***. The first thickness t1 is different from the second thickness t2. The first thickness t1 is set in accordance with a first resonance frequency of the first vibration film **72*a***. The second thickness t2 is set in accordance with a second resonance frequency of the second vibration film **72*b***. In this way, the thicknesses t1, t2 of the acoustic matching layer **55** are optimized for each of the first vibration film **72*a*** and the second vibration film **72*b***.

Herein, for the determination of the thicknesses t1, t2 of the acoustic matching layer **55**, the first vibration film **72***a* has a first film thickness p1, and the second vibration film **72***b* has a second film thickness p2. The second film thickness p2 is larger than the first film thickness p1.

[0082] For fabrication of the ultrasonic device **17***c*, an oxide film is formed on the surface of the substrate **61** when forming the film material **62**. Silicon of the substrate **61** is oxidized to silicon oxide. In this way, the film thickness of the oxide film can be set individually for each region by controlling the oxidation amount for each region. In this way, it is possible to increase the film thickness of the oxide film for regions corresponding to the second vibration film **72***b*. It is possible to form the film material **62** having the first film thickness p1 and the second film thickness p2. Subsequently, the first openings **78***a* and the second openings **78***b* are formed from the rear surface of the substrate **61**, allowing the silicon oxide layer **51** to function as an etching stop layer at a portion different from the rear surface of the substrate **61** in the first openings **78***a* and the second openings **78***b*. Thereby, it is possible to form the first openings **78***a* with a depth corresponding to the first thickness t1, and the second openings **78***b* with a depth corresponding to the second thickness t2. The surface of the raw material **64** injected into the first openings **78***a* and the second openings **78***b* extends in a plane. Accordingly, the fluid has different thicknesses at portions corresponding to the first vibration film **72***a* and portions corresponding to the second vibration film **72***b*. Thereby, it is possible to control the thicknesses t1, t2 of the acoustic matching layer.

[0083] On the other hand, as shown in the above embodiment, the acoustic matching layer **55** may have the same thickness at the first openings **78***a* and the second openings **78***b*. Ordinarily, the thickness of the acoustic matching **55** corresponds to an odd multiple of a quarter of a wavelength of the ultrasonic wave. If the harmonic relationship between the first resonance frequency and the second resonance frequency is satisfied, then acoustic matching can be achieved even when the same thickness is selected at the first openings **78***a* and the second openings **78***b*.

[0084] Although some embodiments of the invention have been described above in detail, those skilled in the art will readily understand that various modifications may be made without substantially departing from the new items and the effects of the invention. Therefore, such modifications are entirely included within the scope of the invention. For example, any term described at least once together with a broader or synonymous different term in the specification or the drawing may be replaced by the different term at any place in the specification or the drawings. Besides, configurations and operations of the terminal device **12**, the ultrasonic probe **13**, the housing **16**, the display panel **15** and so forth are not limited to those described in the present embodiment, but may be modified in various ways.

[0085] The entire disclosure of Japanese Patent Application No. 2013-240276 filed on Nov. 20, 2013 is expressly incorporated by reference herein.

What is claimed is:

1. A ultrasonic device comprising:

a substrate which has a first opening, a second opening and a wall part partitioning the first opening and the second opening,

a first vibration film and a second vibration film which close the first opening and the second opening respectively,

a first piezoelectric element and a second piezoelectric element which are respectively formed on surfaces of the first vibration film and the second vibration film opposite to the substrate, and

an acoustic matching layer which is disposed within the first opening and the second opening so as to be in contact with the first vibration film and the second vibration film.

2. The ultrasonic device according to claim **1**, wherein a plurality of the first openings are disposed in a row, and wherein a plurality of the second first openings are disposed in a row parallel to the arrangement of the first openings.

3. The ultrasonic device according to claim **1**, wherein the wall part has a first wall part with a first height in a thickness direction of the substrate and a second wall part with a second height that is larger than the first height.

4. The ultrasonic device according to claim **3**, further provided with an acoustic lens which is in contact with the second wall part and coupled to the acoustic matching layer.

5. The ultrasonic device according to claim **3**, wherein the acoustic matching layer is disposed between the acoustic lens and the first wall part.

6. The ultrasonic device according to claim **1**, further provided with an exterior frame which surrounds the first opening and the second opening consecutively in a plan view viewed from a thickness direction of the substrate and has a height that is larger than the wall part with respect to the thickness direction of the substrate.

7. The ultrasonic device according to claim **1**, wherein the first vibration film has a first resonance frequency and the second vibration film has a second resonance frequency different from the first resonance frequency.

8. The ultrasonic device according to claim **7**, wherein the acoustic matching layer has the same thickness at the first opening and the second opening.

9. The ultrasonic device according to claim **7**, wherein the acoustic matching layer has different thicknesses at the first opening and the second opening.

10. A probe comprising the ultrasonic device according to claim **1**, and a housing supporting the ultrasonic device.

11. An electronic device comprising the ultrasonic device according to claim **1**, and a processing device which is connected to the ultrasonic device and processes an output of the ultrasonic device.

12. An ultrasonic imaging device comprising the ultrasonic device according to claim **1**, and a display device which displays an image created from an output of the ultrasonic device.

13. A method for manufacturing an ultrasonic device comprising:

forming a first piezoelectric element and a second piezoelectric element on a surface of a film material which is provided on a first surface of a substrate,

forming a first opening and a second opening which are separated from each other with a wall part from a second surface on a rear side with respect to the first surface of the substrate, and forming a first vibration film supporting the first piezoelectric element and a second vibration film supporting the second piezoelectric element on the film material,

injecting a fluid raw material of an acoustic matching layer into the first opening and the second opening, and

covering the injected fluid with an acoustic lens, and curing the fluid to attach the acoustic lens.

14. The method for manufacturing the ultrasonic device according to claim **13**, wherein the wall part has a first wall part with a first height in a thickness direction of the substrate and a second wall part with a second height larger than the first height.

15. The method for manufacturing the ultrasonic device according to claim **13**, further comprising forming the first vibration film with a first film thickness and the second vibration film with a second film thickness from the planar surface of the film material to form the first opening and the second opening.

* * * * *

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专利名称(译)	超声波装置，其制造方法，电子装置和超声波成像装置		
公开(公告)号	US20150141827A1	公开(公告)日	2015-05-21
申请号	US14/541528	申请日	2014-11-14
[标]申请(专利权)人(译)	精工爱普生株式会社		
申请(专利权)人(译)	SEIKO EPSON CORPORATION		
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IPC分类号	B06B1/06 H01L41/33 A61B8/14 A61B8/00 B06B3/04 H01L41/053		
CPC分类号	B06B1/0622 B06B3/04 H01L41/053 H01L41/33 A61B8/4488 A61B8/461 A61B8/14 A61B8/4427 A61B8/4483 A61B8/4494 B06B1/064 Y10T29/42		
优先权	2013240276 2013-11-20 JP		
其他公开文献	US9818929		
外部链接	Espacenet USPTO		

摘要(译)

一种超声波装置，包括：基板，具有第一开口，第二开口和分隔第一开口和第二开口的壁部;第一振动膜和第二振动膜，分别封闭第一开口和第二开口;第一压电元件和第二压电元件，形成在第一振动膜和第二振动膜的与基板相对的表面上;声匹配层设置在第一开口和第二开口内，以便与第一振动膜和第二振动膜接触。