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(54) **ULTRASONIC TRANSDUCER**

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(57) **ABSTRACT**

An ultrasonic transducer (**1**) includes a base portion (**14**), a piezoelectric element (**11**), a vibration plate (**10**), and a resonator (**12**). The resonator (**12**) is joined to a first surface (**21**) of the vibration plate (**10**). A surface, of the piezoelectric element (**11**), on a side opposite to a side on which the piezoelectric element is joined to the base portion (**14**), is joined to a second surface (**22**) of the vibration plate (**10**). A through-hole (**30**) is formed in the piezoelectric element (**11**) so as to penetrate therethrough in a thickness direction of the vibration plate (**10**). In a planar direction orthogonal to the thickness direction of the vibration plate (**10**), a joined portion (**40**) between the vibration plate (**10**) and the resonator (**12**) is located inward of a node (**20**) of vibration of the vibration plate (**10**), and the through-hole (**30**) is located inward of the node (**20**).

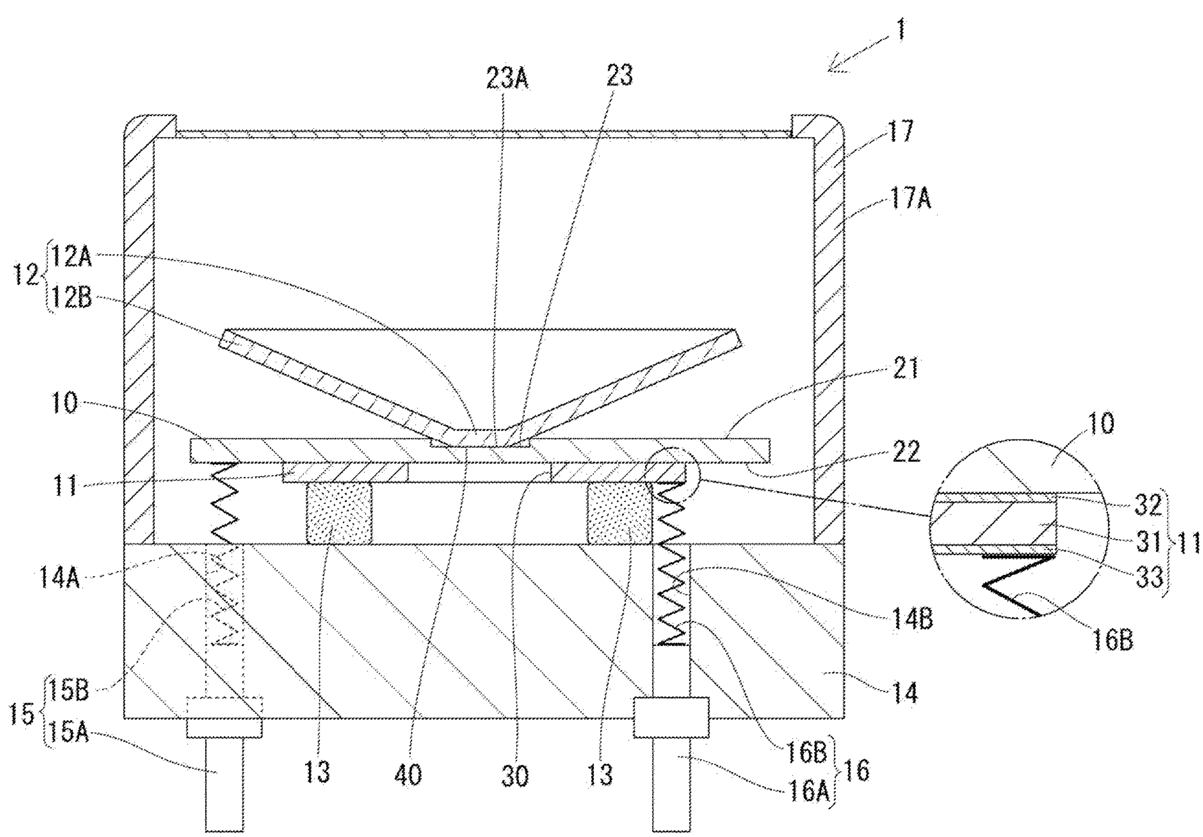
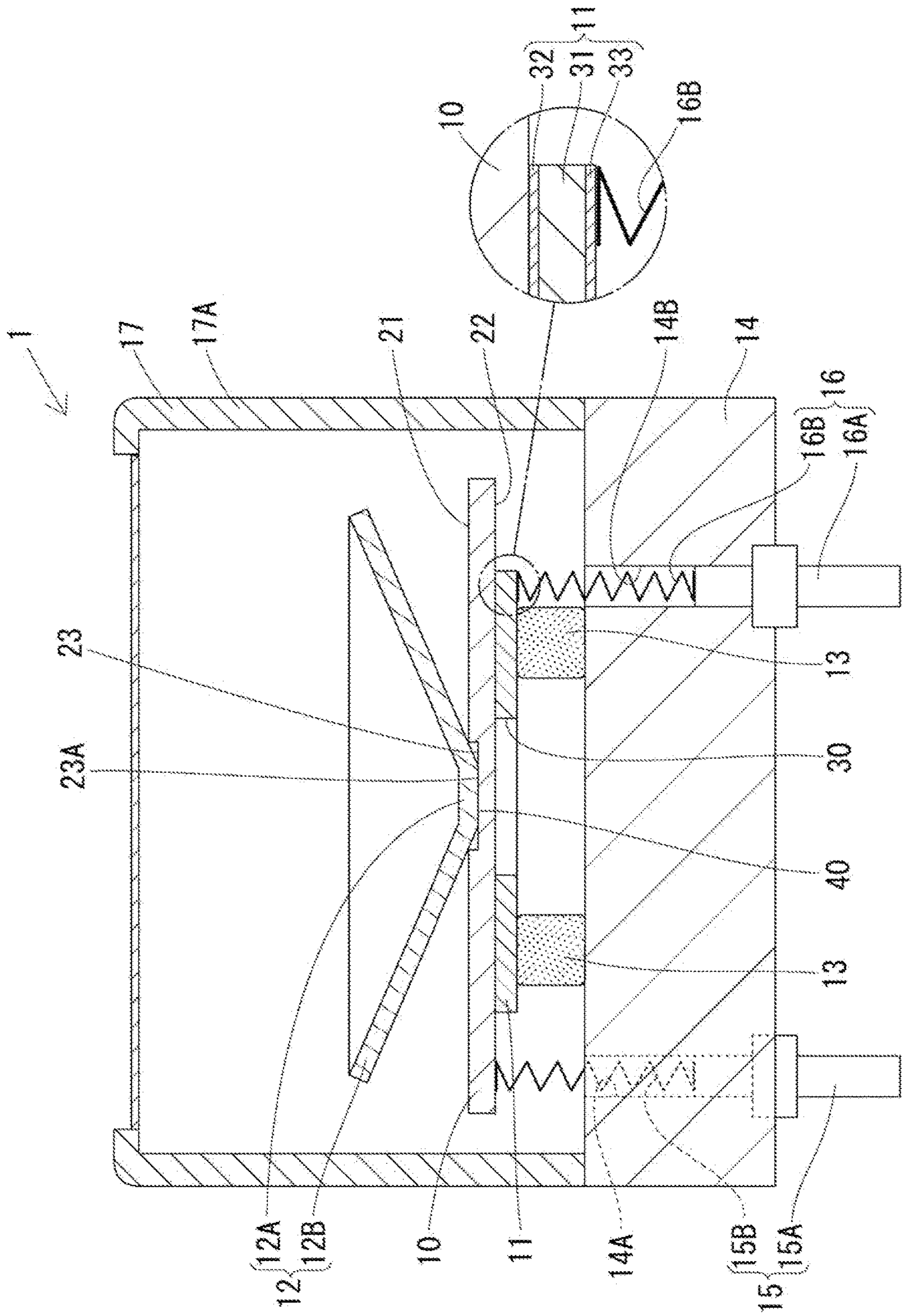


Fig. 1


1
17
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15
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Fig. 2

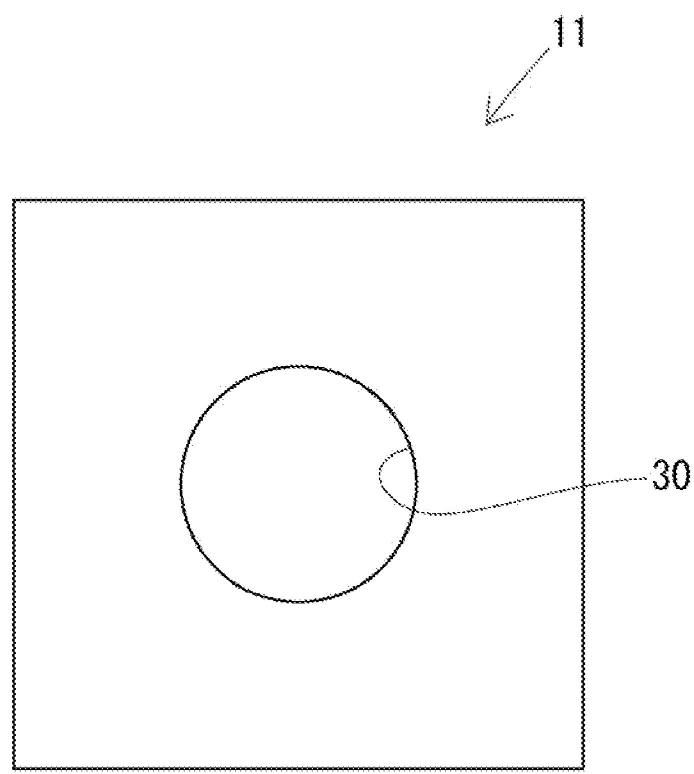


Fig. 3

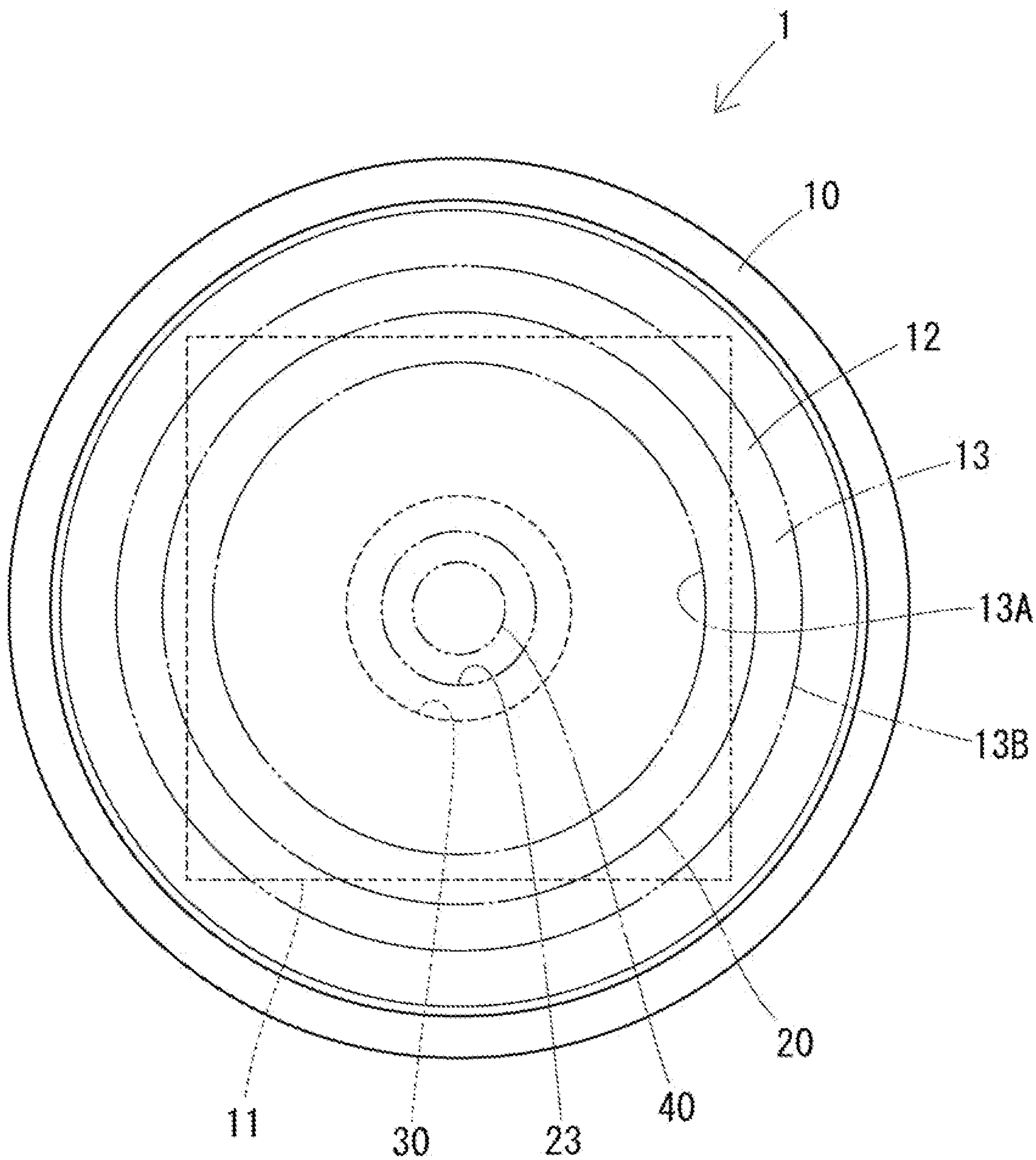


Fig. 4

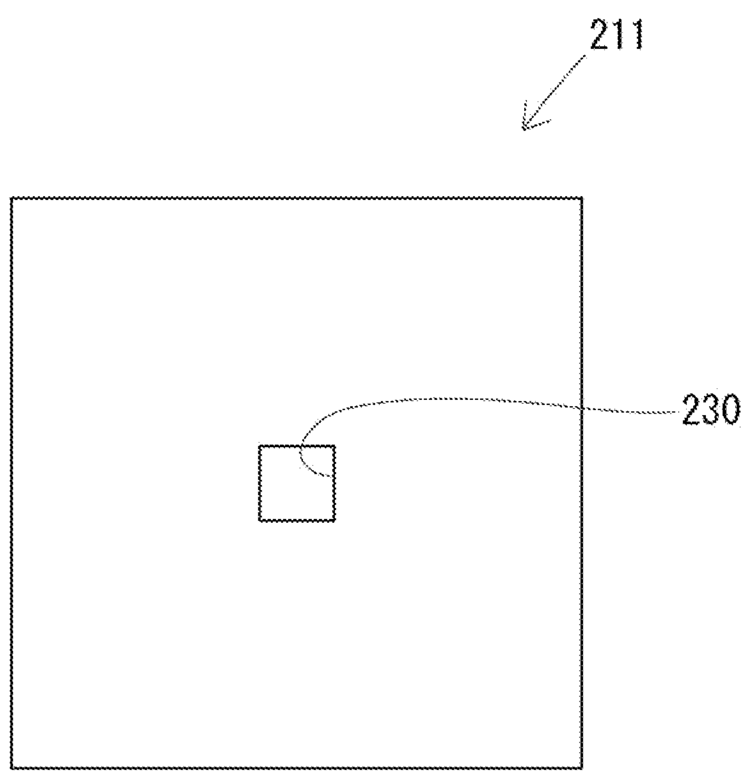


Fig. 5

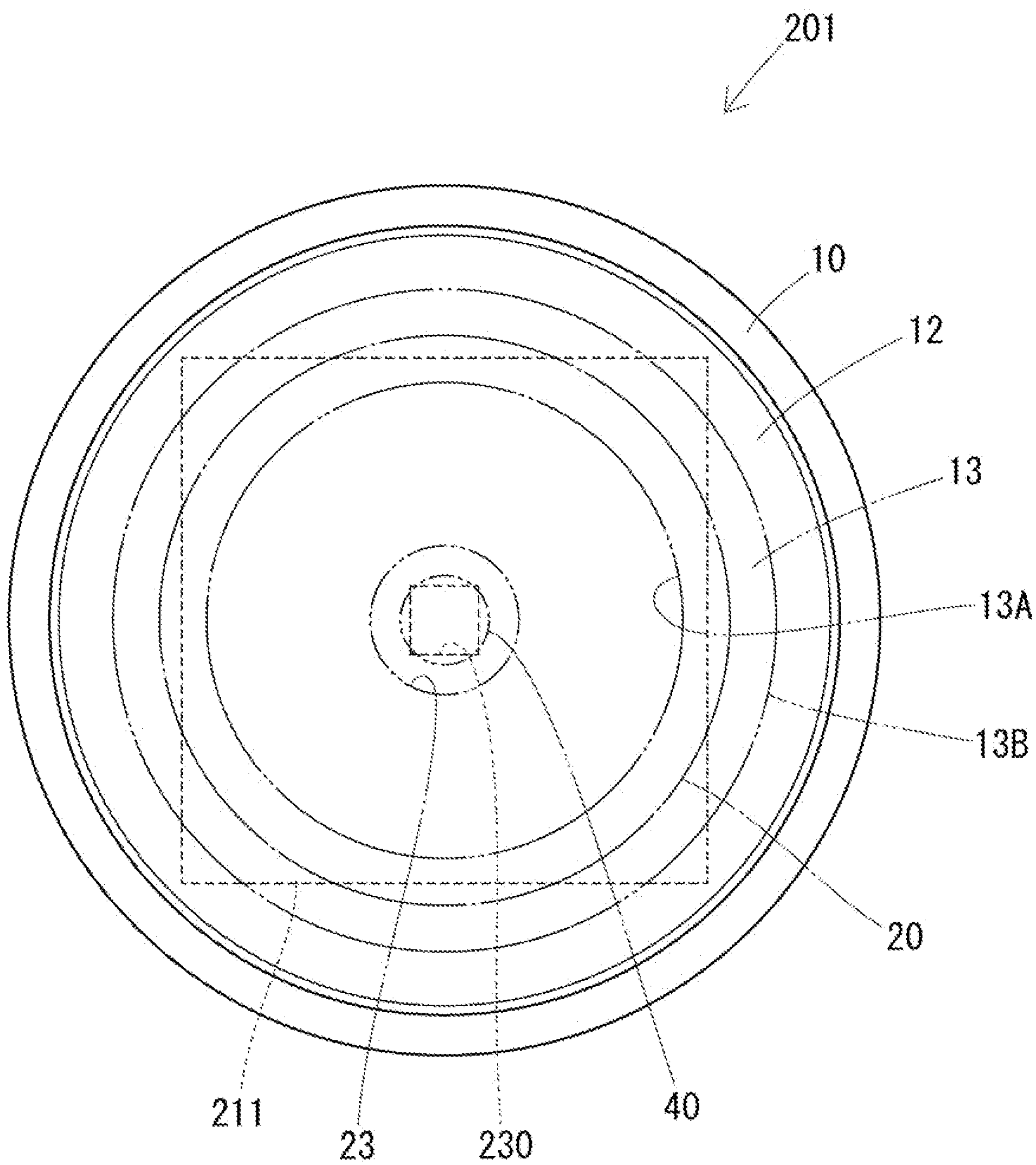


Fig. 6

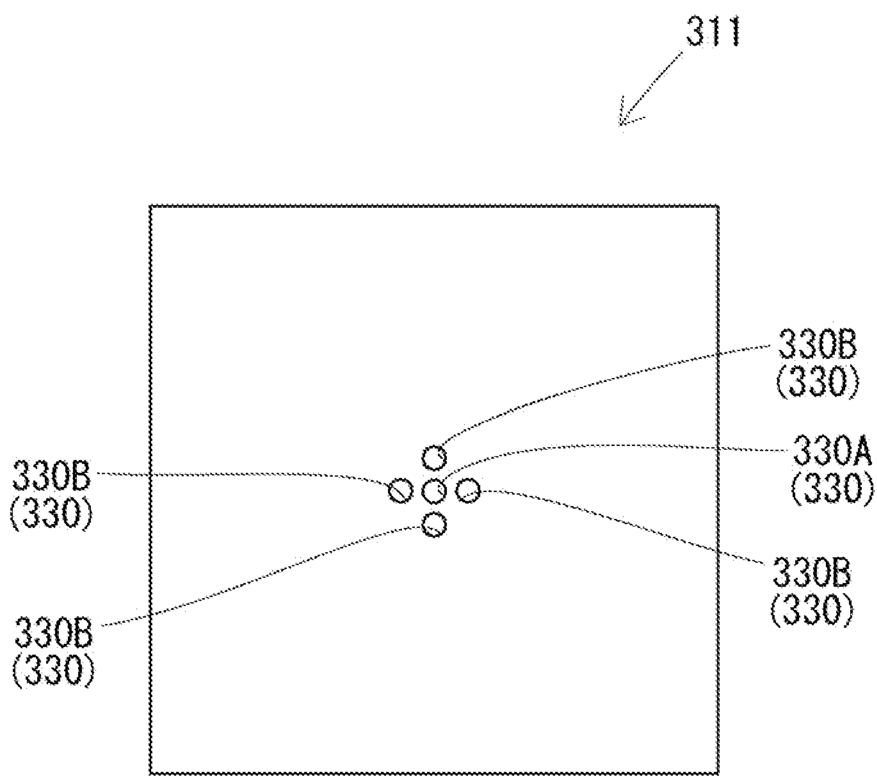


Fig. 7

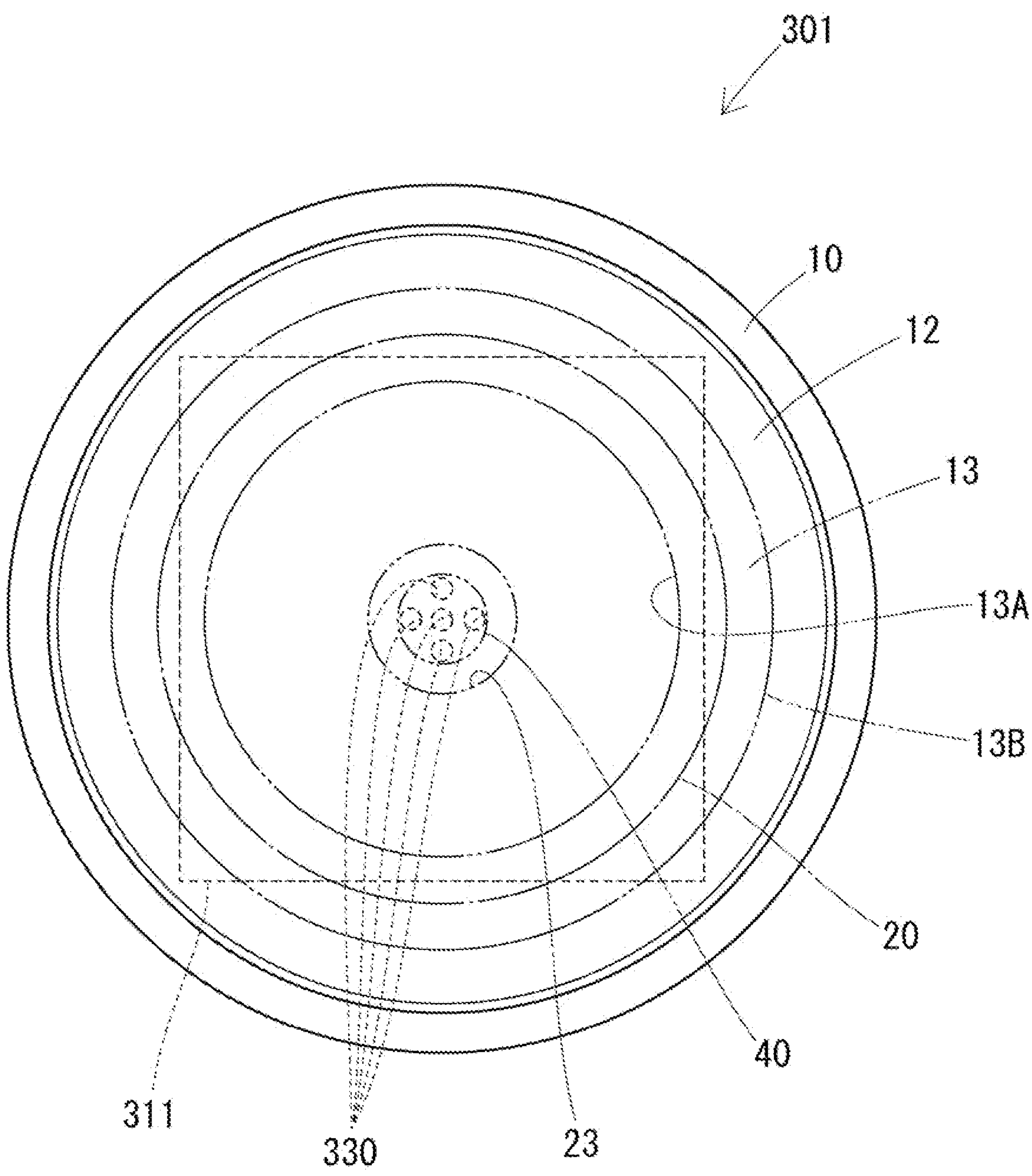


Fig. 8

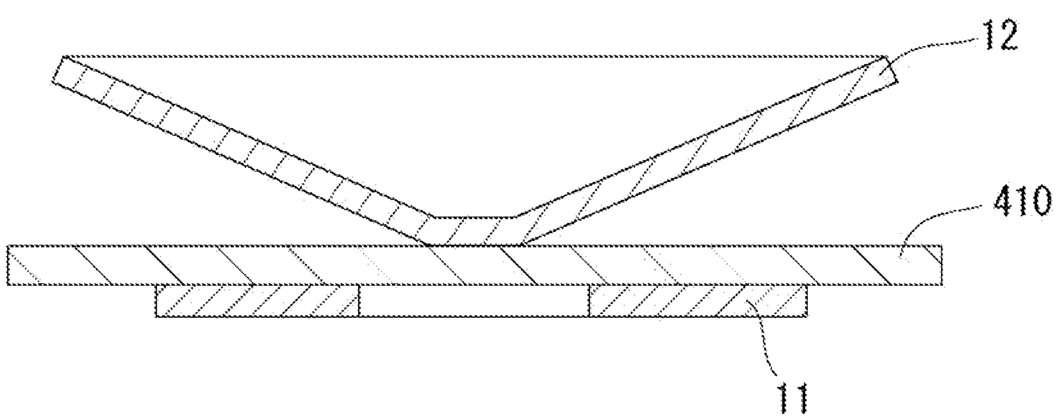


Fig. 9

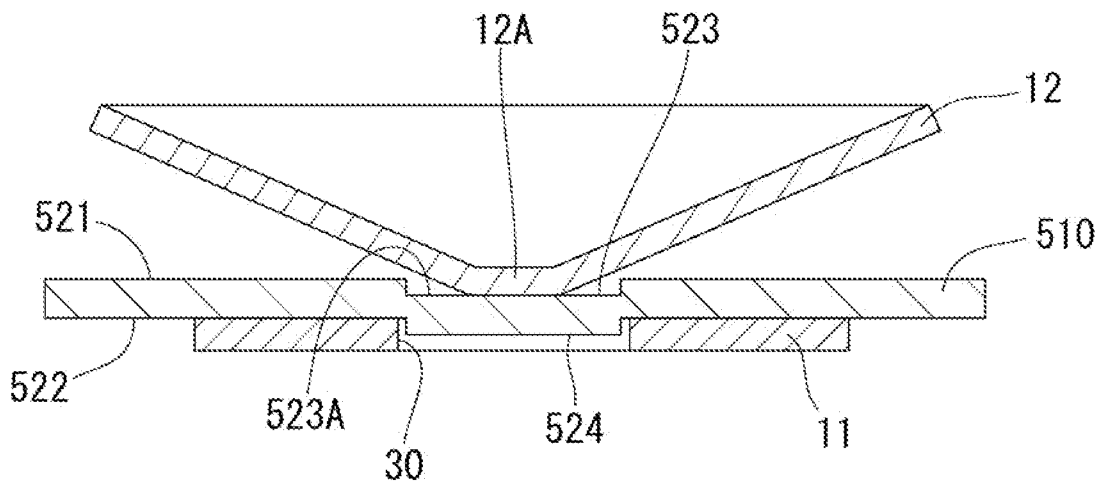
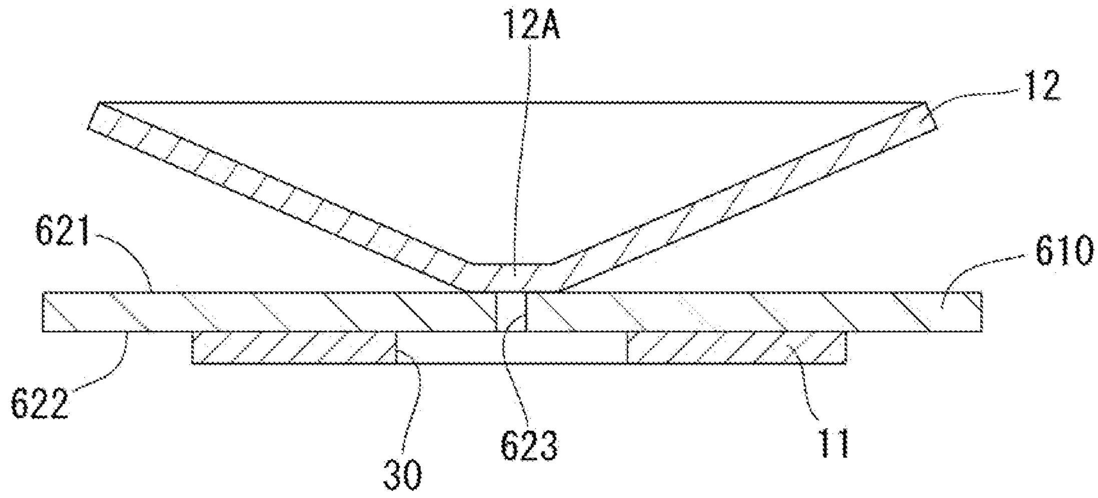


Fig. 10



ULTRASONIC TRANSDUCER

TECHNICAL FIELD

[0001] The present disclosure relates to an ultrasonic transducer.

BACKGROUND ART

[0002] Patent Document 1 discloses an ultrasonic transducer. The ultrasonic transducer includes: a piezoelectric vibrating body obtained by joining a piezoelectric body and a metal to each other with an adhesive; and a funnel-like resonator fixed to the piezoelectric vibrating body. The piezoelectric vibrating body is fixed onto a base member with a buffer member interposed therebetween.

PRIOR ART DOCUMENT

Patent Document

[0003] Patent Document 1: Japanese Patent Application Laid-Open (kokai) No. 2001-258098

SUMMARY OF THE INVENTION

Problem to be Solved by the Invention

[0004] In this type of ultrasonic transducer, when the ultrasonic transducer is driven, the resonator vibrates so that stress is easily applied to the piezoelectric body (piezoelectric element) at around a joined portion between the resonator and the metal (vibration plate). Therefore, there is a concern that, for example, the piezoelectric body (piezoelectric element) suffers a crack or damage as a result of repetitively driving the ultrasonic transducer.

[0005] An object of the present disclosure is to provide technologies that enable decrease in stress that is applied to a piezoelectric element owing to vibration of a resonator.

Means for Solving the Problem

[0006] [1] A first ultrasonic transducer of the present invention includes: a base portion; a piezoelectric element joined to the base portion; a vibration plate joined to the piezoelectric element and configured to vibrate so as to generate an annular node; and a resonator joined to the vibration plate. The resonator is joined to a first surface, of the vibration plate, on one side in a thickness direction thereof. A surface, of the piezoelectric element, on a side opposite to a side on which the piezoelectric element is joined to the base portion, is joined to a second surface, of the vibration plate, on another side in the thickness direction thereof. A through-hole is formed in the piezoelectric element so as to penetrate therethrough in the thickness direction. In a planar direction orthogonal to the thickness direction, a joined portion between the vibration plate and the resonator is located inward of the node, and the through-hole is located inward of the node.

[0007] In this ultrasonic transducer, the joined portion between the vibration plate and the resonator is located inward of the node of vibration of the vibration plate. Due to this, stress is easily applied to the piezoelectric element on the inner side relative to the node. However, the through-hole of the piezoelectric element is formed in the region to which the stress from the joined portion is easily applied. Therefore, this ultrasonic transducer makes it possible to decrease stress that is applied to the piezoelectric element owing to vibration of the resonator.

[0008] [2] A second ultrasonic transducer of the present invention includes: a base portion; an interposed member having an annular shape and joined to the base portion; a piezoelectric element joined to the base portion with the interposed member interposed therebetween; a vibration plate joined to the piezoelectric element and configured to vibrate so as to generate an annular node; and a resonator joined to the vibration plate. A first surface, of the vibration plate, on one side in a thickness direction thereof is joined to the resonator. A second surface, of the vibration plate, on another side in the thickness direction thereof is joined to a surface, of the piezoelectric element, on a side opposite to a side on which the piezoelectric element is joined to the base portion. A through-hole is formed in the piezoelectric element so as to penetrate therethrough in the thickness direction. In a planar direction orthogonal to the thickness direction, a joined portion between the vibration plate and the resonator is located inward of an inscribed circle inscribed in the interposed member, and the through-hole is located inward of the inscribed circle.

[0009] In this ultrasonic transducer, the joined portion between the vibration plate and the resonator is located inward of the inscribed circle inscribed in the interposed member. Due to this, the vibration plate easily vibrates on the inner side relative to the inscribed circle inscribed in the interposed member, and stress is easily applied to the piezoelectric element on the inner side relative to the inscribed circle. However, the through-hole of the piezoelectric element is formed in the region to which the stress from the joined portion is easily applied. Therefore, this ultrasonic transducer makes it possible to decrease stress that is applied to the piezoelectric element owing to vibration of the resonator.

[0010] [3] At least a part of the joined portion may be located so as to overlap with the through-hole as seen in the thickness direction.

[0011] With this configuration, at least a part of the joined portion is located so as to overlap with the through-hole, and thus stress that is applied to the piezoelectric element owing to vibration of the resonator can be more effectively decreased.

[0012] [4] An entirety of the joined portion may be located so as to overlap with the through-hole as seen in the thickness direction.

[0013] With this configuration, since the entirety of the joined portion is located so as to overlap with the through-hole, stress that is applied to the piezoelectric element owing to vibration of the resonator can be more effectively decreased.

[0014] [5] The vibration plate may have a hole portion, and at least a part of the joined portion may be located so as to overlap with the hole portion as seen in the thickness direction.

[0015] With this configuration, it can be made easy for the vibration plate to vibrate, and the power consumption for causing vibration of the vibration plate can be decreased.

Advantageous Effects of the Invention

[0016] The present invention makes it possible to decrease stress that is applied to the piezoelectric element owing to vibration of the resonator.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. **1** is a cross-sectional view schematically showing an ultrasonic transducer in a first embodiment.

[0018] FIG. **2** is a plan view of a piezoelectric element in the first embodiment.

[0019] FIG. **3** is a plan view of the ultrasonic transducer in the first embodiment.

[0020] FIG. **4** is a plan view of a piezoelectric element in a second embodiment.

[0021] FIG. **5** is a plan view of an ultrasonic transducer in the second embodiment.

[0022] FIG. **6** is a plan view of a piezoelectric element in a third embodiment.

[0023] FIG. **7** is a plan view of an ultrasonic transducer in the third embodiment.

[0024] FIG. **8** is a cross-sectional view of a vibration plate, the piezoelectric element, and a resonator in a fourth embodiment.

[0025] FIG. **9** is a cross-sectional view of a vibration plate, the piezoelectric element, and the resonator in a fifth embodiment.

[0026] FIG. **10** is a cross-sectional view of a vibration plate, the piezoelectric element, and the resonator in a sixth embodiment.

MODES FOR CARRYING OUT THE INVENTION

First Embodiment

[0027] An ultrasonic transducer **1** shown in FIG. **1** is used for, for example, a medical or industrial ultrasonic device. The ultrasonic transducer **1** generates an ultrasonic wave upon receiving a drive signal, and converts, upon receiving an ultrasonic wave, the ultrasonic wave into an electric signal.

[0028] The ultrasonic transducer **1** includes a vibration plate **10**, a piezoelectric element **11**, a resonator **12**, an interposed member **13**, a base portion **14**, a first wiring portion **15**, a second wiring portion **16**, and a case **17**.

[0029] The vibration plate **10** has a plate shape (more specifically, a disc shape). The vibration plate **10** has electrical conductivity. The vibration plate **10** is made of, for example, a metal composed of a material such as 42 Alloy (42Ni—Fe). The width (maximum width) of the vibration plate **10** is larger than the width (maximum width) of each of the resonator **12**, the interposed member **13**, and the piezoelectric element **11**. The width (maximum width) of the vibration plate **10** refers to the length (maximum length) of the vibration plate **10** in a direction orthogonal to a thickness direction thereof. In the present embodiment, the width (maximum width) of the vibration plate **10** is the diameter of the outer circumference of the vibration plate **10**.

[0030] The vibration plate **10** vibrates so as to generate an annular (more specifically, ring-shaped) node **20**. The vibration plate **10** generates only one annular node **20**. The node **20** refers to a portion at which, when the vibration plate **10** vibrates, the displacement amount thereof in the plate thickness direction is smallest or no vibration occurs. The node **20** is uniquely determined according to the shapes and the materials of the vibration plate **10**, the piezoelectric element **11**, and the resonator **12**. In FIG. **1**, the piezoelectric element **11** is expressed in an exaggerated manner so as to look large, but is much smaller than the vibration plate **10** and the resonator **12**, in actuality. Thus, the position of the node **20** is roughly determined according to the shapes and the materials of the vibration plate **10** and the resonator **12**, and the shape and the material of the piezoelectric element **11** inflict little influence on determination of the position of the node **20**. The outer circumferential edge of the vibration plate **10** is a free end. That is, the ultrasonic transducer **1** is of a so-called opened type and more easily vibrates than an ultrasonic transducer of a closed type in which the outer circumferential edge of the vibration plate **10** is fixed. The node **20** is generated inward of the outer circumferential edge of the vibration plate **10** and outward of the center of the vibration plate **10**, in a planar direction orthogonal to the plate thickness direction. Vibration of the vibration plate **10** becomes more intense from the node **20** toward the outer circumferential edge and becomes more intense from the node **20** toward the center.

[0031] The vibration plate **10** has a first surface **21** on one side in the thickness direction and a second surface **22** on another side in the thickness direction. The resonator **12** is joined to the first surface **21**. The piezoelectric element **11** is joined to the second surface **22**. In the present description, the term “joined” conceptually encompasses not only a configuration in which joining is directly performed but also a configuration in which joining is performed via another member.

[0032] The vibration plate **10** has a hole portion **23**. The hole portion **23** is formed in the first surface **21** and has a shape obtained by recessing the first surface **21**. The hole portion **23** is formed by, for example, cutting. A cross section of the hole portion **23** taken along a plane orthogonal to the thickness direction of the vibration plate **10** has a circular shape and is unchanging in the thickness direction of the vibration plate **10**.

[0033] The resonator **12** generates an ultrasonic wave by resonating according to vibration of the vibration plate **10**. The resonator **12** has a function of increasing the efficiency of transmission of a sonic wave of the vibration plate **10** excited upon periodic power supply to the piezoelectric element **11**. The resonator **12** is made of, for example, a metal composed of a material such as an aluminum alloy. The resonator **12** is joined to the vibration plate **10**. The method for the joining is not limited and, for example, may involve adhesion with use of an adhesive such as an epoxy adhesive, or may involve soldering, ultrasonic welding, laser welding, or the like. The resonator **12** has a cone shape. The resonator **12** has a flat portion **12**A and a tapered portion **12**B. The flat portion **12**A is flat and has a plate shape (more specifically, a disc shape). The flat portion **12**A is joined to the first surface **21** of the vibration plate **10**. The flat portion **12**A has a shape for allowing the flat portion **12**A to be accommodated in the hole portion **23** and is joined to a bottom surface **23**A of the hole portion **23** formed in the first surface **21**. The tapered portion **12**B cylindrically extends from the outer circumferential edge of the flat portion **12**A toward a side opposite to the vibration plate **10** side. The tapered portion **12**B has a tapered shape such that the inner circumferential surface thereof becomes wider toward the side opposite to the vibration plate **10** side.

[0034] The piezoelectric element **11** has a plate shape and is joined so as to be stacked on the vibration plate **10**. The piezoelectric element **11** is joined to the vibration plate **10** with use of a thermosetting epoxy adhesive or the like. As shown in FIG. **2**, the piezoelectric element **11** has a rectangular shape as seen in the thickness direction of the vibration plate **10**. A through-hole **30** is formed in the piezoelectric element **11** so as to penetrate therethrough in the thickness direction of the vibration plate **10**. A cross section of the through-hole **30** taken along a plane in a direction orthogonal to the direction of the penetration has a circular shape. As shown in FIG. **1**, the piezoelectric element **11** has a piezoelectric body **31** having a plate shape and electrodes **32** and **33** provided on both respective sides in the thickness direction of the piezoelectric body **31**. The piezoelectric body **31** is made of, for example, a ceramic such as lead zirconate titanate (PZT) or potassium sodium niobate (KNN). The electrode **32** which is one of the electrodes **32** and **33** provided to both sides of the piezoelectric element **11** is joined to the vibration plate **10** and electrically connected to the first wiring portion **15** via the vibration plate **10**. The electrode **33** which is the other one, different from the electrode **32**, of the electrodes provided to both sides of the piezoelectric element **11** is electrically connected to the second wiring portion **16**. To a surface, of the piezoelectric element **11**, on the side opposite to the vibration plate **10** side, the base portion **14** is joined with the interposed member **13** interposed therebetween.

[0035] The interposed member **13** is disposed between the piezoelectric element **11** and the base portion **14** and joined to each of the piezoelectric element **11** and the base portion **14**. The interposed member **13** has insulating properties and elasticity. The interposed member **13** has a lower Young's modulus than the base portion **14**. The interposed member **13** is made of, for example, a rubber such as silicone rubber, a resin such as a silicon-based adhesive, or the like. The interposed member **13** has an annular shape (more specifically, a ring shape). An axial direction of the interposed member **13** extends along the thickness direction of the vibration plate **10**, and more specifically, coincides with the thickness direction of the vibration plate **10**. The interposed member **13** is disposed such that the node **20** of vibration of the vibration plate **10** is located between an inscribed circle **13**A inscribed in the interposed member **13** and a circumcircle **13**B circumscribing the interposed member **13** in the planar direction orthogonal to the plate thickness direction of the vibration plate **10** (see FIG. **3**).

[0036] The base portion **14** is made of a synthetic resin and is formed as a resin base. The base portion **14** has a plate shape. A thickness direction of the base portion **14** extends along the thickness direction of the vibration plate **10**, and more specifically, coincides with the thickness direction of the vibration plate **10**.

[0037] The first wiring portion **15** has a first terminal **15**A and a first coil spring **15**B each made of a metal. A first base through-hole **14**A is formed in the base portion **14** so as to penetrate therethrough in the thickness direction. The first wiring portion **15** is inserted through the first base through-hole **14**A. The first terminal **15**A is fixed to the base portion **14** at a position at which an opening, of the first base through-hole **14**A, on the side opposite to the vibration plate **10** side is closed. An expansion/contraction direction of the first coil spring **15**B extends along the thickness direction of the vibration plate **10**, and more specifically, coincides with the thickness direction. The first coil spring **15**B is sandwiched between the vibration plate **10** and the first terminal **15**A, and is disposed in a state of being compressed by being pressed from the vibration plate **10** and the first terminal **15**A. The first coil spring **15**B has one end in contact with the vibration plate **10** and has another end in contact with the first terminal **15**A. The first wiring portion **15** is electrically connected to one electrically-conductive path out of a positive-electrode-side electrically-conductive path and a negative-electrode-side electrically-conductive path (for example, a ground).

[0038] The second wiring portion **16** has a second terminal **16**A and a second coil spring **16**B each made of a metal. A second base through-hole **14**B is formed in the base portion **14** so as to penetrate therethrough in the thickness direction. The second wiring portion **16** is inserted through the second base through-hole **14**B. The second terminal **16**A is fixed to the base portion **14** at a position at which an opening, of the second base through-hole **14**B, on the side opposite to the vibration plate **10** side is closed. An expansion/contraction direction of the second coil spring **16**B extends along the thickness direction of the vibration plate **10**, and more specifically, coincides with the thickness direction. The second coil spring **16**B is sandwiched between the piezoelectric element **11** and the second terminal **16**A, and is disposed in a state of being compressed by being pressed from the piezoelectric element **11** and the second terminal **16**A. The second coil spring **16**B has one end in contact with a surface, of the piezoelectric element **11**, on the side opposite to the vibration plate **10** side (i.e., the electrode **33** of the piezoelectric element **11**) and has another end in contact with the second terminal **16**A. The second wiring portion **16** is electrically connected to the other electrically-conductive path out of the positive-electrode-side electrically-conductive path and the negative-electrode-side electrically-conductive path (for example, the ground).

[0039] The case **17** is a member for protecting the resonator **12** so as not to allow foreign matter to come into contact with the resonator **12**. The case **17** is fixed to the base portion **14**. The case **17** has a peripheral wall portion **17**A enclosing the surrounding of the resonator **12**. A plurality of openings is formed, in the case **17**, on a side opposite to the base portion **14** side relative to the resonator **12**. Through the openings, ultrasonic waves are transmitted to outside and ultrasonic waves enter the case **17** from outside.

[0040] As shown in FIG. **3**, in the planar direction orthogonal to the thickness direction of the vibration plate **10**, a joined portion **40** between the vibration plate **10** and the resonator **12** is located inward of the node **20**, and the through-hole **30** of the piezoelectric element **11** is located inward of the node **20**. In addition, in the planar direction, the joined portion **40** between the vibration plate **10** and the resonator **12** is located inward of the inscribed circle **13**A inscribed in the interposed member **13**, and the through-hole **30** is located inward of the inscribed circle **13**A. In addition, the entirety of the joined portion **40** is located so as to overlap with the through-hole **30** as seen in the thickness direction of the vibration plate **10**. In addition, the entirety of the joined portion **40** is located so as to overlap with the hole portion **23** as seen in the thickness direction of the vibration plate **10**.

[0041] The following descriptions are related to advantageous effects of the first embodiment.

[0042] In the ultrasonic transducer **1** in the first embodiment, the joined portion **40** between the vibration plate **10** and the resonator **12** is located inward of the node **20** of vibration of the vibration plate **10**. Due to this, stress is easily applied to the piezoelectric element **11** on the inner side relative to the node **20**. However, the through-hole **30**

of the piezoelectric element **11** is formed in the region to which the stress from the joined portion **40** is easily applied. Therefore, this ultrasonic transducer **1** makes it possible to decrease stress that is applied to the piezoelectric element **11** owing to vibration of the resonator **12**.

[0043] In addition, in the ultrasonic transducer **1** in the first embodiment, the joined portion **40** between the vibration plate **10** and the resonator **12** is located inward of the inscribed circle **13**A inscribed in the interposed member **13**. Due to this, the vibration plate **10** easily vibrates on the inner side relative to the inscribed circle **13**A inscribed in the interposed member **13**, and stress is easily applied to the piezoelectric element **11** on the inner side relative to the inscribed circle **13**A. However, the through-hole **30** of the piezoelectric element **11** is formed in the region to which the stress from the joined portion **40** is easily applied. Therefore, this ultrasonic transducer **1** makes it possible to decrease stress that is applied to the piezoelectric element **11** owing to vibration of the resonator **12**.

[0044] Furthermore, the entirety of the joined portion **40** is located so as to overlap with the through-hole **30** as seen in the thickness direction of the vibration plate **10**. Since the entirety of the joined portion **40** is located so as to overlap with the through-hole **30**, stress that is applied to the piezoelectric element **11** owing to vibration of the resonator **12** can be more effectively decreased.

[0045] Furthermore, the entirety of the joined portion **40** is located so as to overlap with the hole portion **23** as seen in the thickness direction of the vibration plate **10**. Consequently, it can be made easy for the vibration plate **10** to vibrate, and the power consumption for causing vibration of the vibration plate **10** can be decreased.

Second Embodiment

[0046] In the first embodiment, the entirety of the joined portion is located so as to overlap with the through-hole as seen in the thickness direction of the vibration plate. However, the configuration in which the entirety of the joined portion is located so as to overlap with the through-hole does not have to be employed. In a second embodiment, an example in which a part of the joined portion is located so as to overlap with the through-hole as seen in the thickness direction of the vibration plate, will be described. An ultrasonic transducer in the second embodiment differs from the ultrasonic transducer in the first embodiment only in terms of the shape of the piezoelectric element. The other features are common to both ultrasonic transducers. In the following descriptions, the same constituents as those in the first embodiment are denoted by the same reference characters, and detailed explanations thereof are omitted.

[0047] As shown in FIG. **4**, a piezoelectric element **211** in the second embodiment has a rectangular shape as seen in the thickness direction of the vibration plate **10**. A through-hole **230** is formed in the piezoelectric element **211** so as to penetrate therethrough in the thickness direction of the vibration plate **10**. The shape of a cross section of the through-hole **230** taken along a plane orthogonal to the direction of the penetration by the through-hole **230** is a rectangular shape.

[0048] As shown in FIG. **5**, a part of the joined portion **40** between the vibration plate **10** and the resonator **12** is located so as to overlap with the through-hole **230** as seen in the thickness direction of the vibration plate **10**. The through-hole **230** has portions that do not overlap with the joined portion **40** as seen in the thickness direction of the vibration plate **10**.

[0049] As described above, in an ultrasonic transducer **201** in the second embodiment, a part of the joined portion **40** is located so as to overlap with the through-hole **230** as seen in the thickness direction. Consequently, in the ultrasonic transducer **201**, stress that is applied to the piezoelectric element **211** owing to vibration of the resonator **12** can be more effectively decreased as compared with a configuration in which the joined portion **40** is located so as not to overlap with the through-hole **230** at all.

Third Embodiment

[0050] In the first embodiment, the number of through-holes formed in the piezoelectric element is one. However, the number may be two or more. In a third embodiment, an example in which a plurality of through-holes is formed in the piezoelectric element will be described. An ultrasonic transducer in the third embodiment differs from the ultrasonic transducer in the first embodiment only in terms of the shape of the piezoelectric element. The other features are common to both ultrasonic transducers. In the following descriptions, the same constituents as those in the first embodiment are denoted by the same reference characters, and detailed explanations thereof are omitted.

[0051] As shown in FIG. **6**, a piezoelectric element **311** in the third embodiment has a rectangular shape as seen in the thickness direction of the vibration plate **10**. A through-hole **330** is formed in the piezoelectric element **311** so as to penetrate therethrough in the thickness direction of the vibration plate **10**. The shape of a cross section of the through-hole **330** taken along a plane orthogonal to the direction of the penetration by the through-hole **330** is a circular shape. A plurality of (in the present embodiment, five) through-holes **330** is formed in the piezoelectric element **311**. More specifically, one through-hole **330**A is formed at the center of the piezoelectric element **311**, and four through-holes **330**B are formed around the through-hole **330**A.

[0052] As shown in FIG. **7**, a part of the joined portion **40** between the vibration plate **10** and the resonator **12** is located so as to overlap with the through-holes **330** as seen in the thickness direction of the vibration plate **10**.

[0053] As described above, in an ultrasonic transducer **301** in the third embodiment, a part of the joined portion **40** is located so as to overlap with the through-holes **330** as seen in the thickness direction. Consequently, in the ultrasonic transducer **301**, stress that is applied to the piezoelectric element **311** owing to vibration of the resonator **12** can be more effectively decreased as compared with a configuration in which the joined portion **40** is located so as not to overlap with the through-holes **330** at all.

Fourth Embodiment

[0054] The first embodiment employs a configuration in which the vibration plate has a hole portion. However, a configuration in which the vibration plate has no hole portion may be employed. An ultrasonic transducer in a fourth embodiment differs from the ultrasonic transducer in the first embodiment in that the vibration plate has no hole portion. The other features are common to both ultrasonic transducers. In the following descriptions, the same constituents as those in the first embodiment are denoted by the same reference characters, and detailed explanations thereof are omitted.

[0055] As shown in FIG. **8**, the ultrasonic transducer in the fourth embodiment includes a vibration plate **410**, the piezoelectric element **11**, and the resonator **12**. The vibration plate **410** has the same configuration as that of the vibration plate **10** in the first embodiment, except that the vibration plate **410** has no hole portion. That is, both surfaces in the thickness direction of the vibration plate **410** are flat. The thickness of the vibration plate **410** is uniform over the entirety of the vibration plate **410**. In the ultrasonic transducer in the fourth embodiment, the vibration plate **410** has no hole portion, and thus the vibration plate **410** is easily formed.

Fifth Embodiment

[0056] The first embodiment employs a configuration in which the hole portion of the vibration plate is formed by cutting. However, a configuration in which the hole portion of the vibration plate is formed by another method may be employed. In a fifth embodiment, an example in which the hole portion of the vibration plate is formed by half-blanking will be described. An ultrasonic transducer in the fifth embodiment differs from the ultrasonic transducer in the first embodiment in that the hole portion of the vibration plate is formed by half-blanking. The other features are common to both ultrasonic transducers. In the following descriptions, the same constituents as those in the first embodiment are denoted by the same reference characters, and detailed explanations thereof are omitted.

[0057] As shown in FIG. **9**, the ultrasonic transducer in the fifth embodiment includes a vibration plate **510**, the piezoelectric element **11**, and the resonator **12**. The vibration plate **510** has a first surface **521** on one side in the thickness direction and a second surface **522** on another side in the thickness direction. The resonator **12** is joined to the first surface **521**. The piezoelectric element **11** is joined to the second surface **522**.

[0058] The vibration plate **510** has a hole portion **523** and a protruding portion **524**. The hole portion **523** is formed in the first surface **521** and has a shape obtained by recessing the first surface **521**. The hole portion **523** is formed by half-blanking. A cross section of the hole portion **523** taken along a plane orthogonal to the thickness direction of the vibration plate **510** has a circular shape and is unchanging in the thickness direction of the vibration plate **510**. The flat portion **12**A of the resonator **12** is fitted into the hole portion **523** and joined to a bottom surface **523**A of the hole portion **523**.

[0059] The protruding portion **524** is formed on the second surface **522**. At least a part of the protruding portion **524** is located so as to overlap with the hole portion **523** as seen in the thickness direction of the vibration plate **510**. The protruding portion **524** is formed when the hole portion **523** is formed by half-blanking. The protruding portion **524** is fitted into the through-hole **30** of the piezoelectric element **11**. The protrusion dimension of the protruding portion **524** is smaller than the thickness of the piezoelectric element **11**. Therefore, the protruding portion **524** does not protrude outward of the through-hole **30**.

[0060] In the ultrasonic transducer in the fifth embodiment, chips are less likely to be generated as compared with a case where the hole portion of the vibration plate is formed by cutting.

Sixth Embodiment

[0061] The first embodiment employs a configuration in which the hole portion of the vibration plate does not penetrate the vibration plate. However, a configuration in which the hole portion penetrates the vibration plate may be employed. In a sixth embodiment, an example in which the hole portion of the vibration plate penetrates the vibration plate will be described. An ultrasonic transducer in the sixth embodiment differs from the ultrasonic transducer in the first embodiment in that the hole portion of the vibration plate penetrates the vibration plate. The other features are common to both ultrasonic transducers. In the following descriptions, the same constituents as those in the first embodiment are denoted by the same reference characters, and detailed explanations thereof are omitted.

[0062] As shown in FIG. **10**, the ultrasonic transducer in the sixth embodiment includes a vibration plate **610**, the piezoelectric element **11**, and the resonator **12**. The vibration plate **610** has a first surface **621** on one side in the thickness direction and a second surface **622** on another side in the thickness direction. The resonator **12** is joined to the first surface **621**. The piezoelectric element **11** is joined to the second surface **622**.

[0063] The vibration plate **610** has a hole portion **623**. The hole portion **623** is formed so as to penetrate the vibration plate **610** in the thickness direction thereof. The hole portion **623** is located on the inner side relative to the outer circumferential edge of the flat portion **12**A of the resonator **12**, in the planar direction orthogonal to the thickness direction of the vibration plate **610**. The hole portion **623** is located on the inner side relative to the inner wall of the through-hole **30**, in the planar direction orthogonal to the thickness direction of the vibration plate **610**. A cross section of the hole portion **623** taken along a plane orthogonal to the thickness direction of the vibration plate **610** has a circular shape and is unchanging in the thickness direction of the vibration plate **610**.

Other Embodiments

[0064] The present invention is not limited to the embodiments explained by means of the above descriptions and drawings, and, for example, embodiments described below are also encompassed in the technical scope of the present invention. In addition, various features in the above embodiments and the embodiments described later may be combined in any way as long as the combination does not lead to any contradiction.

[0065] Each of the above embodiments employs a configuration in which at least a part of the joined portion is located so as to overlap with the through-hole as seen in the thickness direction of the vibration plate. However, a configuration in which the joined portion is located so as not to overlap with the through-hole at all may be employed.

[0066] Each of the above embodiments employs a configuration in which either of the first coil spring and the second coil spring is not joined. However, a configuration in which these springs are joined may be employed. The method for the joining is not limited and involves, for example, soldering, laser welding, ultrasonic welding, or the like.

[0067] The embodiments disclosed herein are merely illustrative in all aspects and should not be recognized as being restrictive. The scope of the present invention is not limited by the embodiments disclosed herein and is intended to encompass the scope defined by the claims and all modifications made within the scope equivalent to the scope of the claims.

DESCRIPTION OF REFERENCE NUMERALS

[0068] **1**: ultrasonic transducer
[0069] **10**: vibration plate
[0070] **11**: piezoelectric element
[0071] **12**: resonator
[0072] **12**A: flat portion
[0073] **12**B: tapered portion
[0074] **13**: interposed member
[0075] **13**A: inscribed circle
[0076] **13**B: circumcircle
[0077] **14**: base portion
[0078] **14**A: first base through-hole
[0079] **14**B: second base through-hole
[0080] **15**: first wiring portion
[0081] **15**A: first terminal
[0082] **15**B: first coil spring
[0083] **16**: second wiring portion
[0084] **16**A: second terminal
[0085] **16**B: second coil spring
[0086] **17**: case
[0087] **17**A: peripheral wall portion
[0088] **20**: node
[0089] **21**: first surface
[0090] **22**: second surface
[0091] **23**: hole portion
[0092] **23**A: bottom surface
[0093] **30**: through-hole
[0094] **31**: piezoelectric body
[0095] **32**: electrode
[0096] **33**: electrode
[0097] **40**: joined portion
[0098] **201**: ultrasonic transducer
[0099] **211**: piezoelectric element
[0100] **230**: through-hole
[0101] **301**: ultrasonic transducer
[0102] **311**: piezoelectric element
[0103] **330**: through-hole
[0104] **330**A: through-hole
[0105] **330**B: through-hole
[0106] **410**: vibration plate
[0107] **510**: vibration plate
[0108] **521**: first surface
[0109] **522**: second surface
[0110] **523**: hole portion
[0111] **610**: vibration plate
[0112] **621**: first surface
[0113] **622**: second surface
[0114] **623**: hole portion

1. An ultrasonic transducer comprising:
a base portion;
a piezoelectric element joined to the base portion;
a vibration plate joined to the piezoelectric element and configured to vibrate so as to generate an annular node; and
a resonator joined to the vibration plate, wherein
the resonator is joined to a first surface, of the vibration plate, on one side in a thickness direction thereof,
a surface, of the piezoelectric element, on a side opposite to a side on which the piezoelectric element is joined to the base portion, is joined to a second surface, of the vibration plate, on another side in the thickness direction thereof,
a through-hole is formed in the piezoelectric element so as to penetrate therethrough in the thickness direction, and,
in a planar direction orthogonal to the thickness direction, a joined portion between the vibration plate and the resonator is located inward of the node, and the through-hole is located inward of the node.

2. An ultrasonic transducer comprising:
a base portion;
an interposed member having an annular shape and joined to the base portion;
a piezoelectric element joined to the base portion with the interposed member interposed therebetween;
a vibration plate joined to the piezoelectric element and configured to vibrate so as to generate an annular node; and
a resonator joined to the vibration plate, wherein
a first surface, of the vibration plate, on one side in a thickness direction thereof is joined to the resonator,
a second surface, of the vibration plate, on another side in the thickness direction thereof is joined to a surface, of the piezoelectric element, on a side opposite to a side on which the piezoelectric element is joined to the base portion,
a through-hole is formed in the piezoelectric element so as to penetrate therethrough in the thickness direction, and,
in a planar direction orthogonal to the thickness direction, a joined portion between the vibration plate and the resonator is located inward of an inscribed circle inscribed in the interposed member, and the through-hole is located inward of the inscribed circle.

3. The ultrasonic transducer according to claim **1**, wherein
at least a part of the joined portion is located so as to overlap with the through-hole as seen in the thickness direction.

4. The ultrasonic transducer according to claim **3**, wherein
an entirety of the joined portion is located so as to overlap with the through-hole as seen in the thickness direction.

5. The ultrasonic transducer according to claim **1**, wherein
the vibration plate has a hole portion, and
at least a part of the joined portion is located so as to overlap with the hole portion as seen in the thickness direction.

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