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TAKAHASHI et al.

(54) **PIEZOELECTRIC VIBRATING PIECE, PIEZOELECTRIC DEVICE, AND METHOD FOR MANUFACTURING PIEZOELECTRIC DEVICE**

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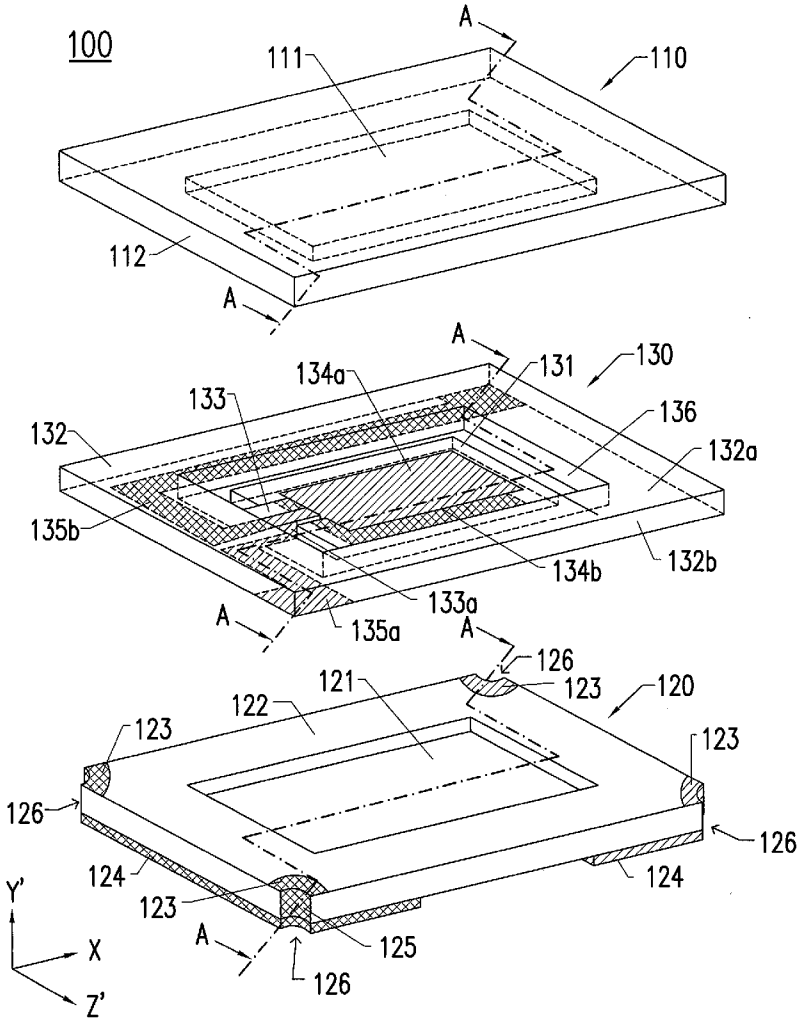
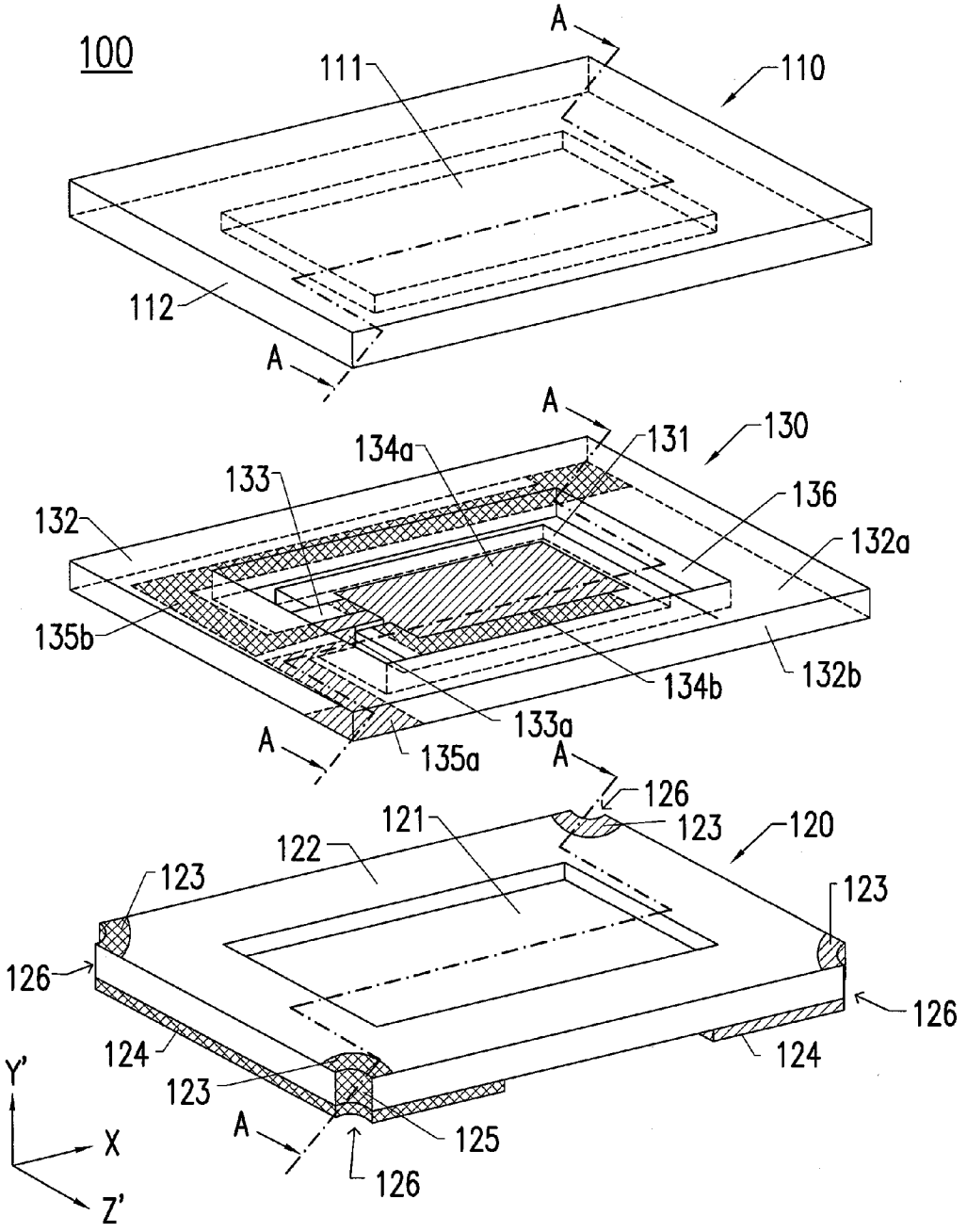
(57) **ABSTRACT**

A piezoelectric vibrating piece is to be bonded to and sandwiched between a lid plate and a base plate with an external electrode. The piezoelectric vibrating piece has a first main surface at the lid plate side and a second main surface at the base plate side. The piezoelectric vibrating piece includes an excitation unit, a first excitation electrode, a second excitation electrode, a framing portion, one connecting portion, a first extraction electrode, and a second extraction electrode. The connecting portion includes a planar surface parallel to both the main surfaces and a side face intersecting with the planar surface. The first extraction electrode is extracted via the connecting portion. The second extraction electrode is extracted via the connecting portion. The first extraction electrode is disposed on at least a part of the side face of the connecting portion to be extracted to the framing portion.

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134a
133
136
132
132a
135b
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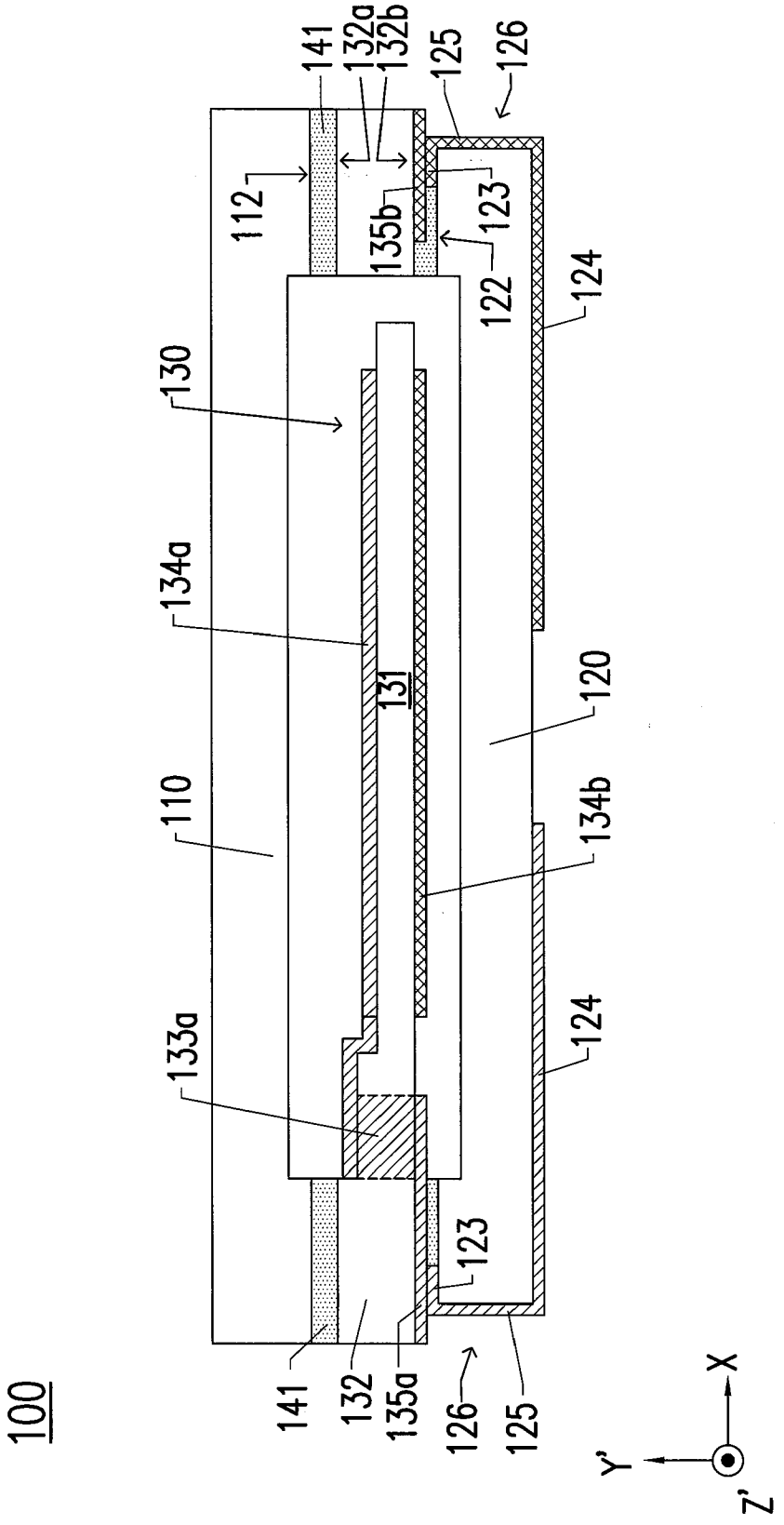
132b
133a
135a
126
123
121
122
120
124
125
Y'
X
Z'

FIG. 1


100
141
132a
132b
125
126
112
135b
123
122
124
130
134a
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110
134b
133a
124
123
141
132
135a
126
125
Y'
X
Z'

FIG. 2

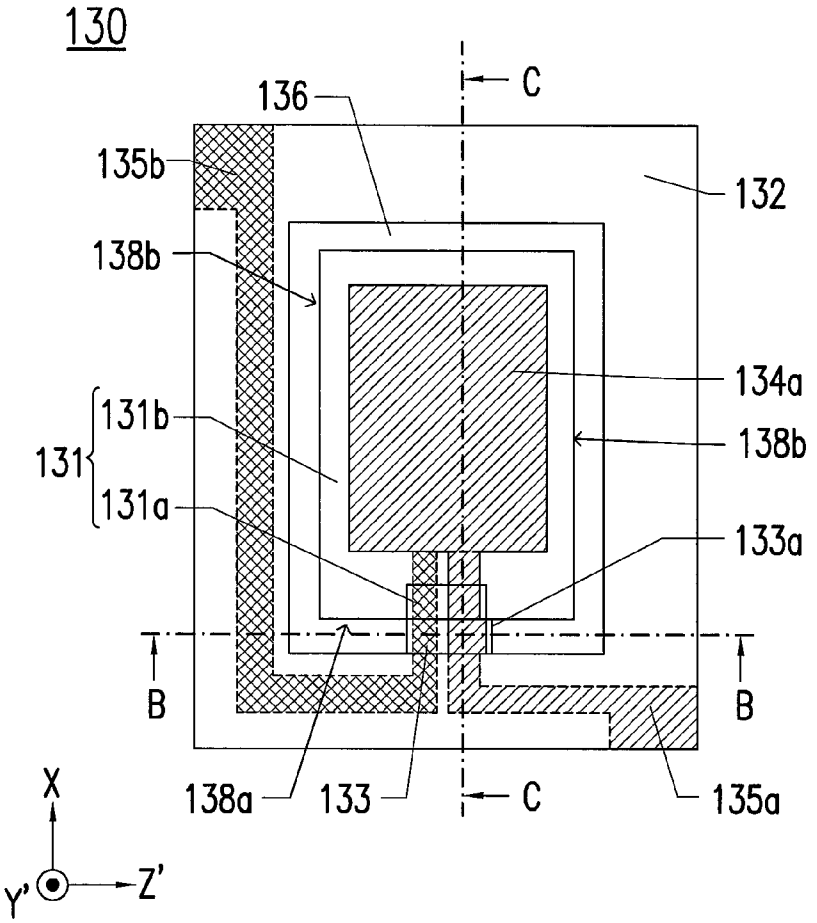
130
136
C
135b
132
138b
134a
131b
131
138b
131a
133a
B
B
X
138a
133
C
135a
Y'
Z'

FIG. 3A

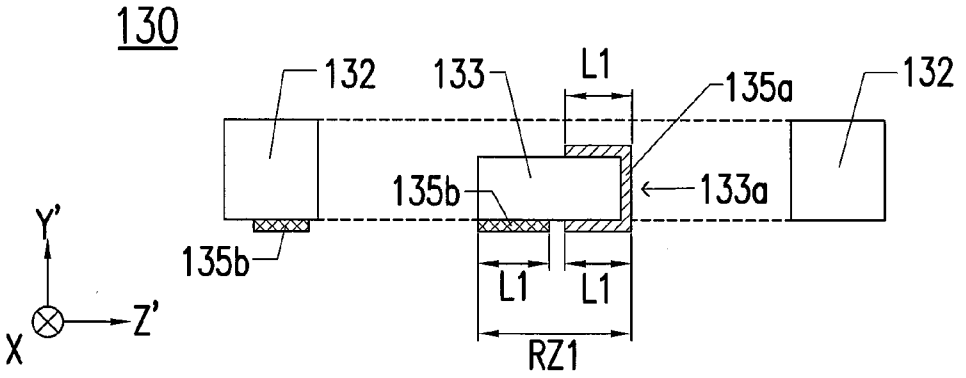
130
132
133
L1
135a
132
135b
133a
Y'
135b
L1
L1
X
Z'
RZ1

FIG. 3B

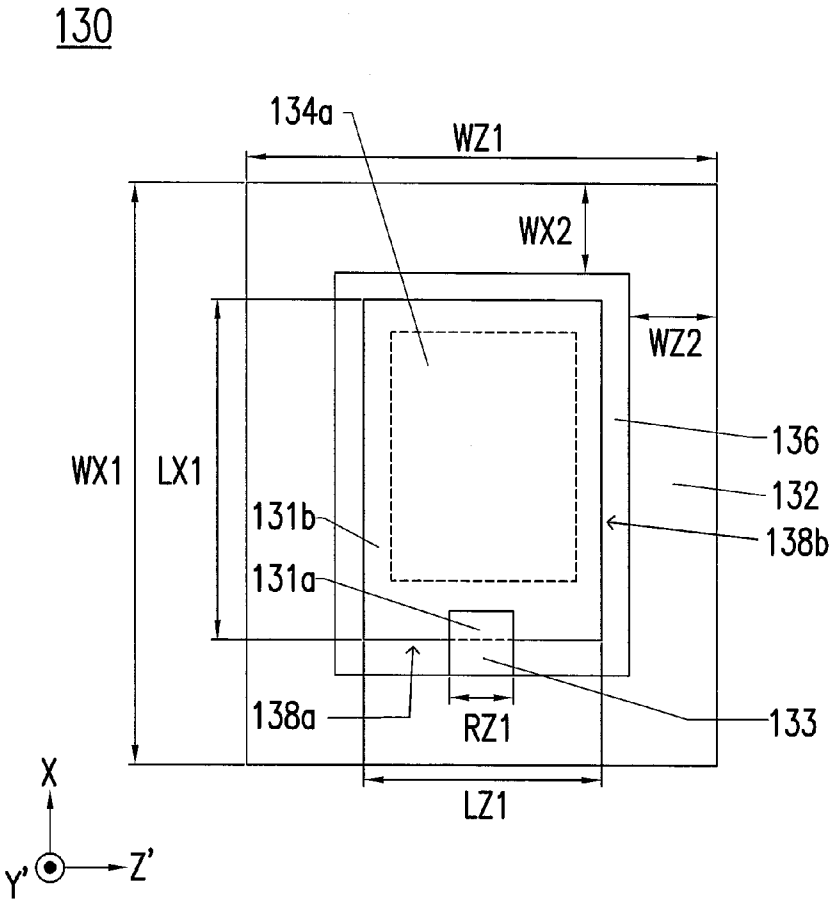
130
134a
WZ1
WX2
WZ2
136
132
138b
131b
131a
WX1
LX1
138a
RZ1
133
LZ1
X
Y'
Z'

FIG. 4A

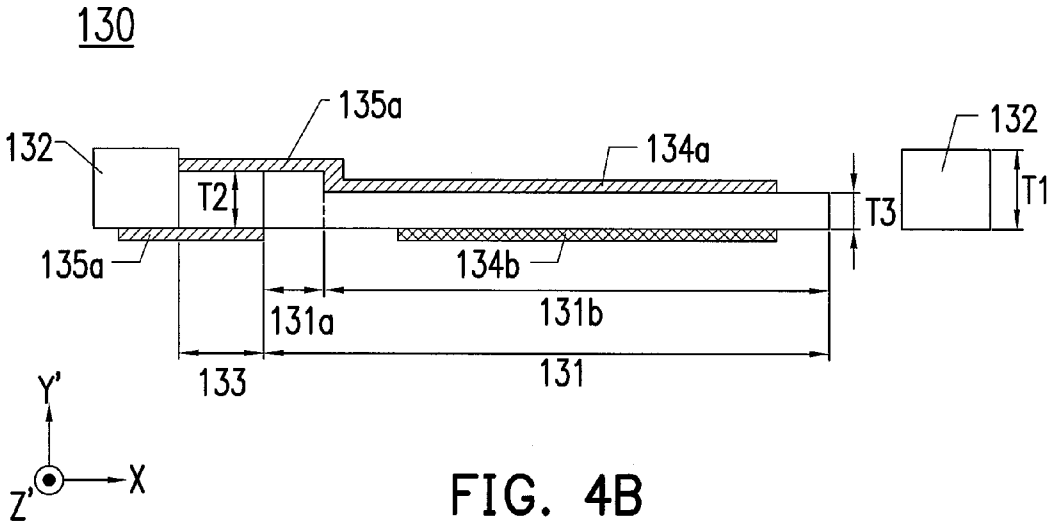
130
135a
132
134a
T2
T3
T1
135a
134b
131a
131b
133
131
Y'
X
Z'

FIG. 4B

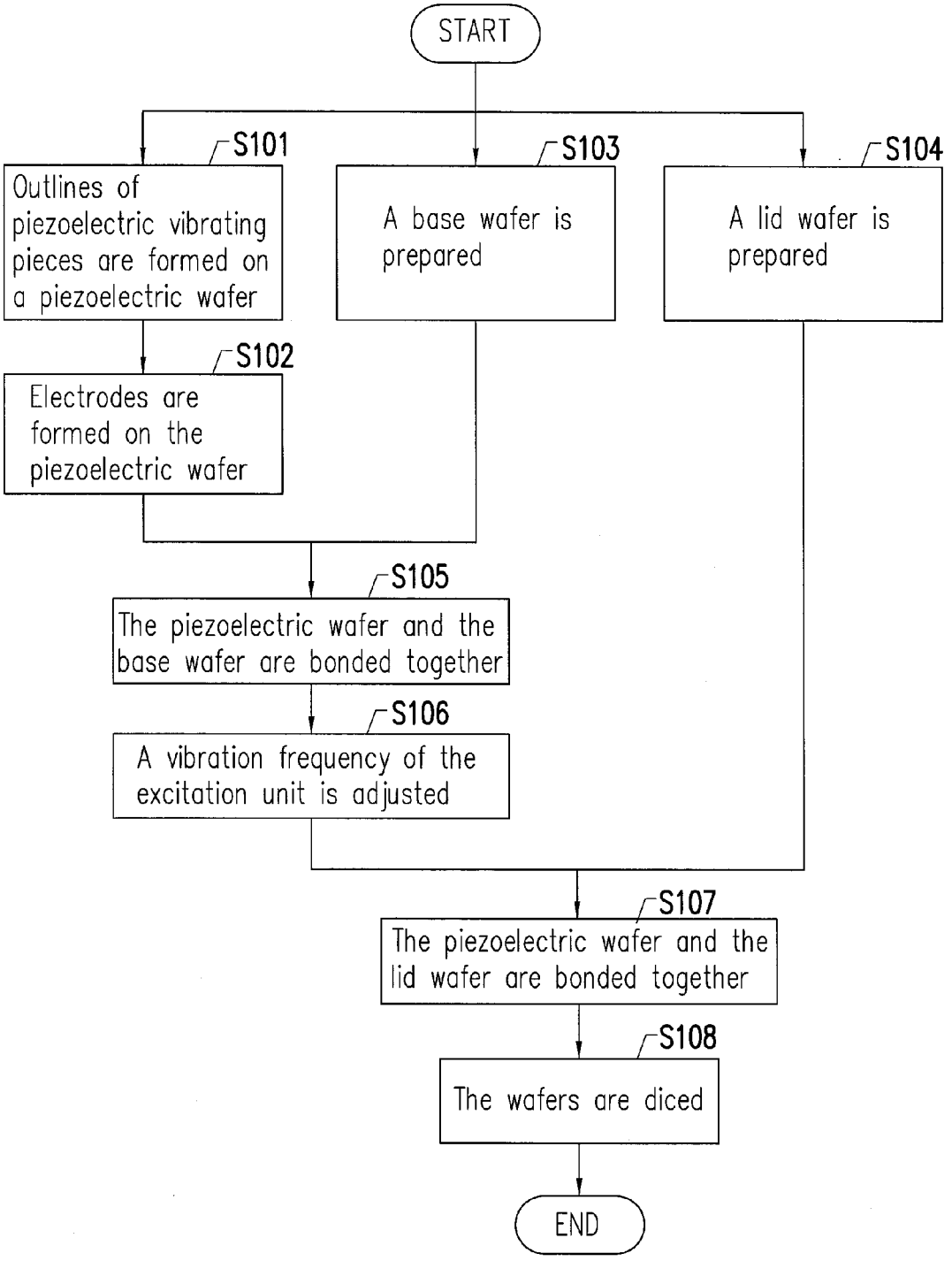
START
S101
Outlines of piezoelectric vibrating pieces are formed on a piezoelectric wafer
S102
Electrodes are formed on the piezoelectric wafer
S103
A base wafer is prepared
S104
A lid wafer is prepared
S105
The piezoelectric wafer and the base wafer are bonded together
S106
A vibration frequency of the excitation unit is adjusted
S107
The piezoelectric wafer and the lid wafer are bonded together
S108
The wafers are diced
END

FIG. 5

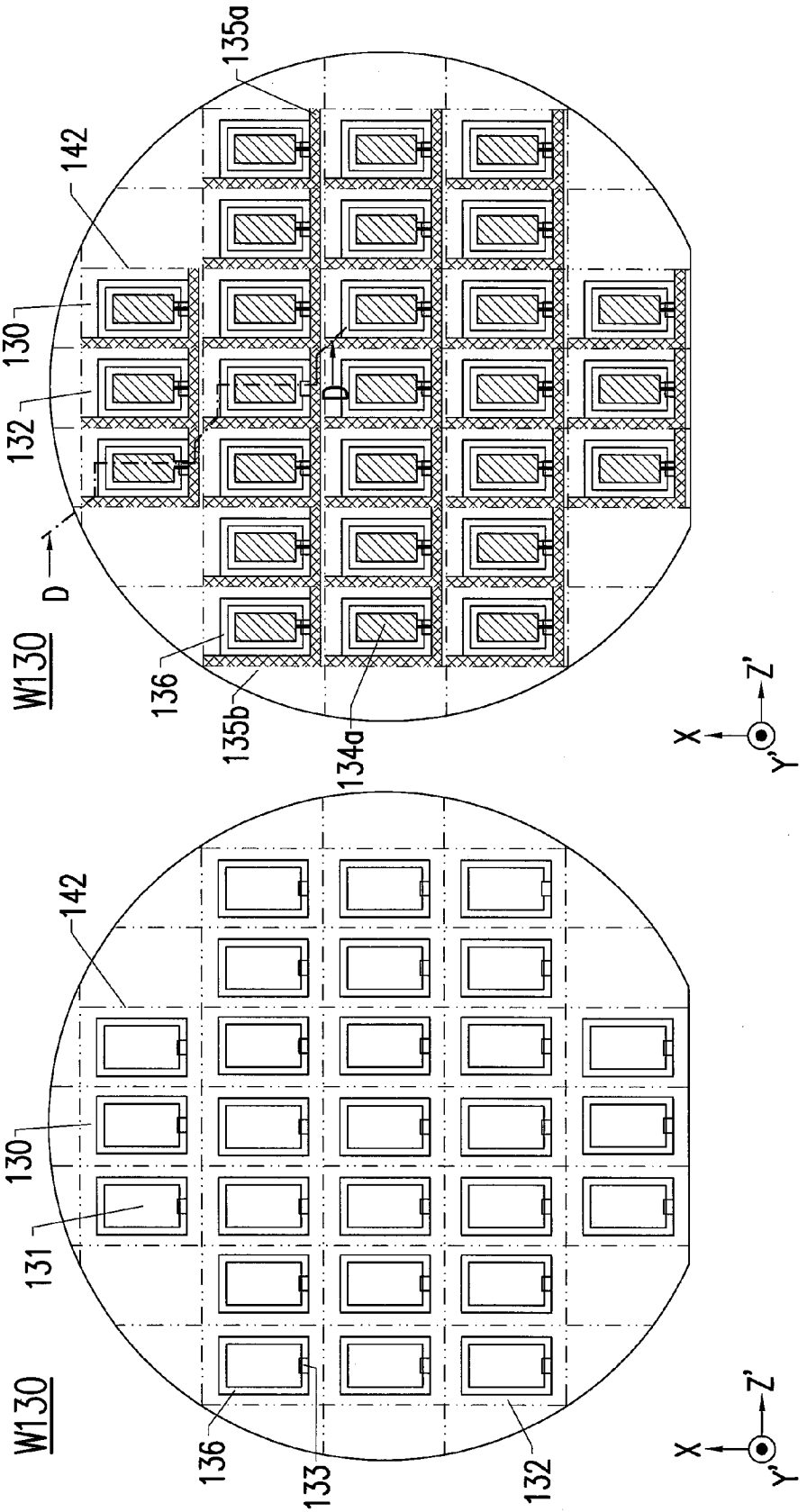
W130
142
130
131
136
133
132
X
Z'
Y'
W130
135a
142
130
132
D
D
136
135b
134a
X
Z'
Y'

FIG. 6A

FIG. 6B

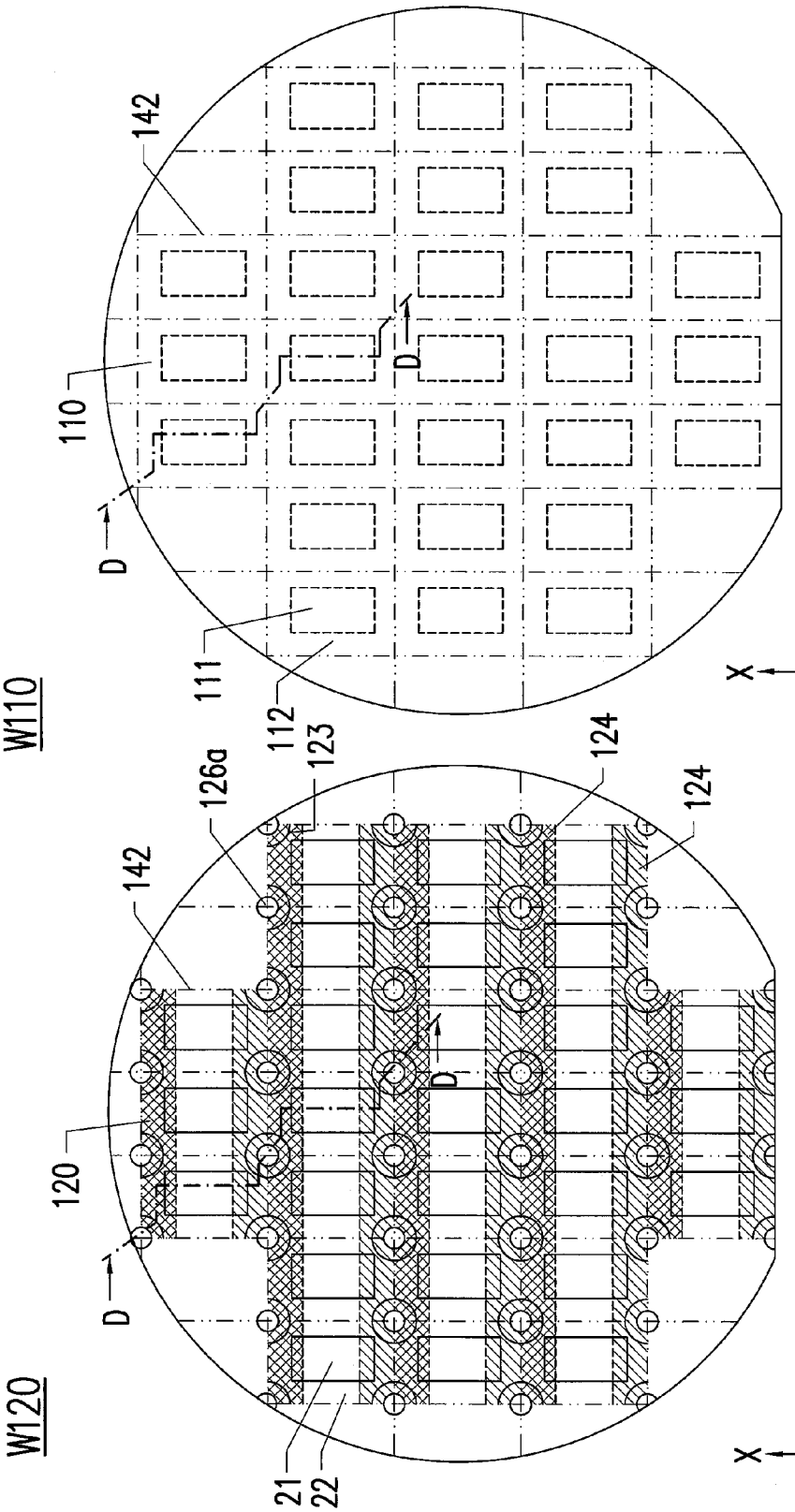
W110
142
110
D
D
111
112
123
126a
124
124
142
120
D
D
121
122
W120
X
Z'
Y'
X
Z'
Y'

FIG. 7B

FIG. 7A

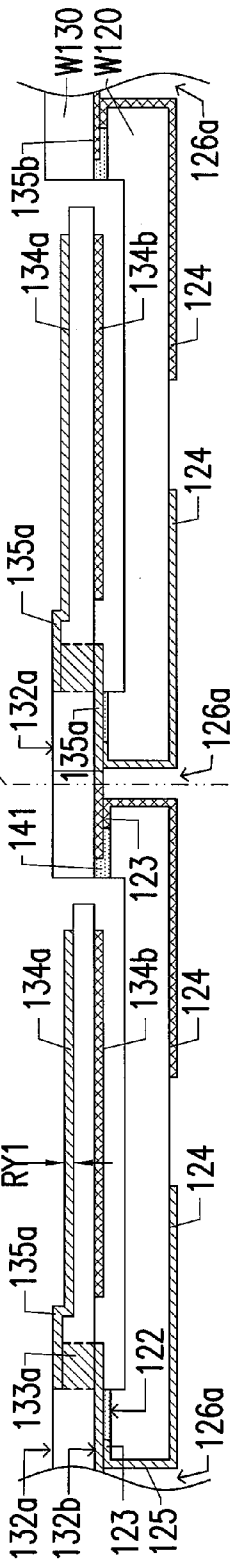

FIG. 8A

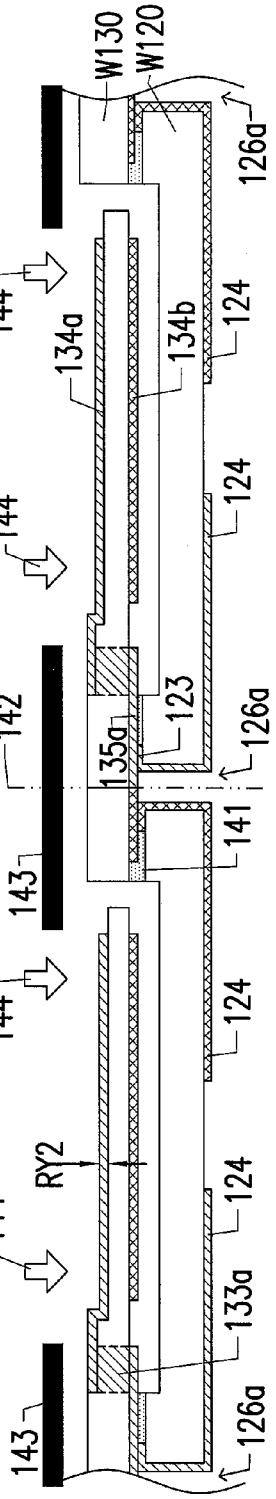

FIG. 8B

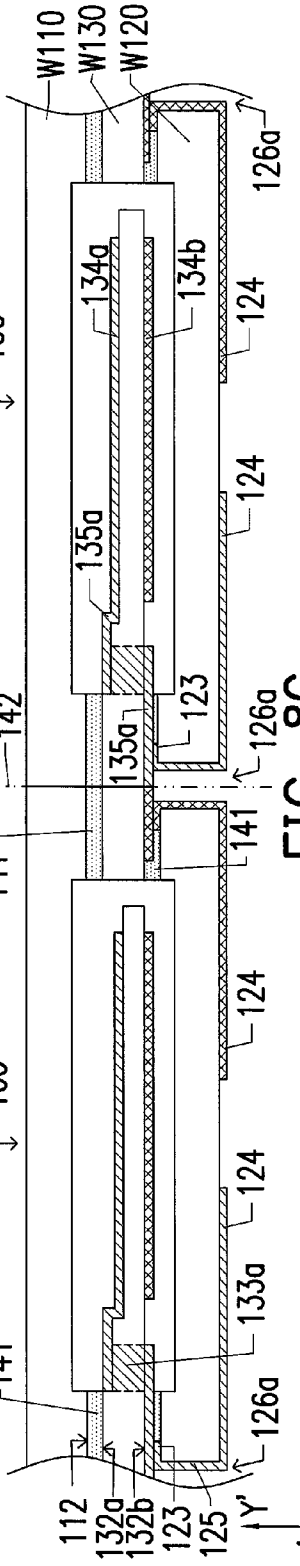

FIG. 8C

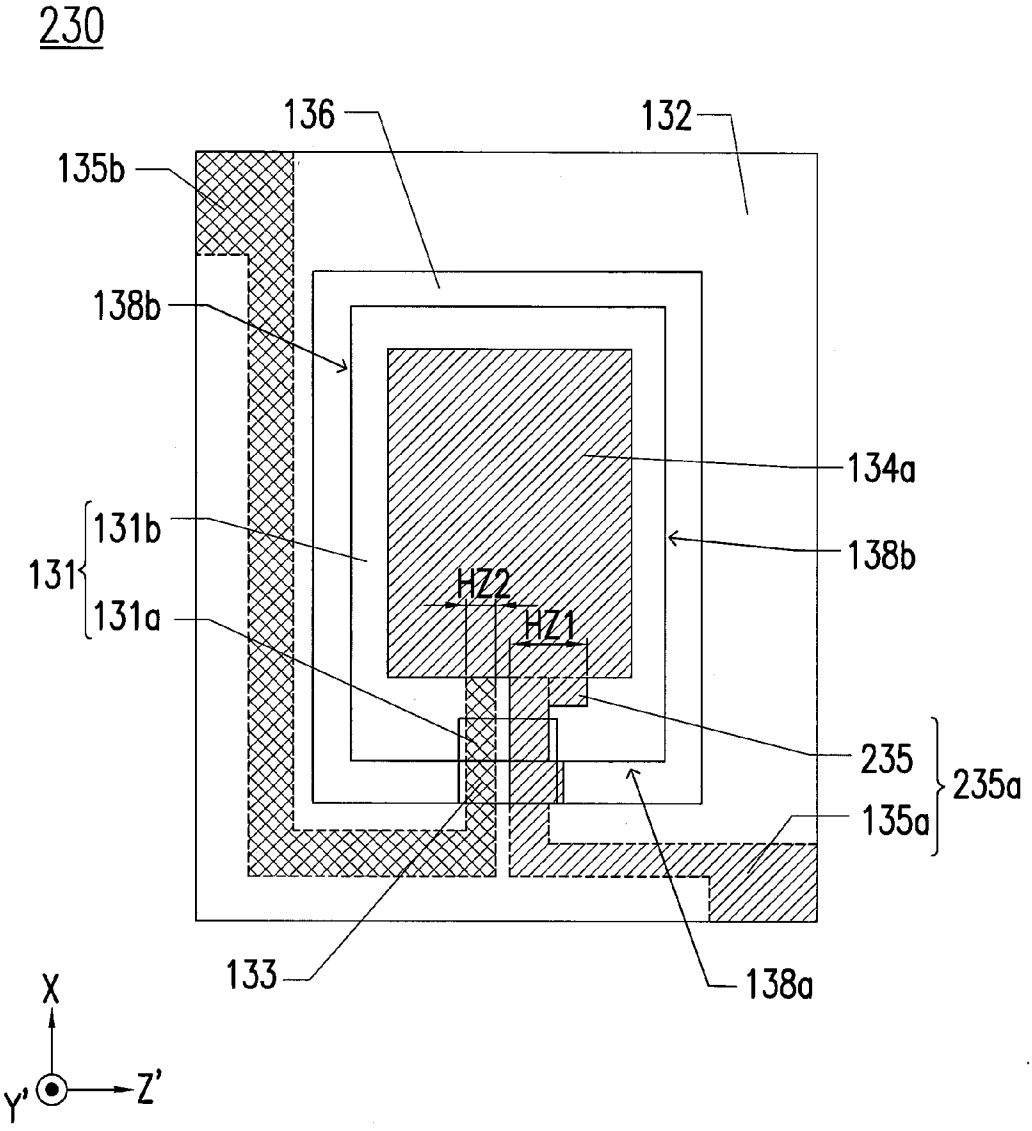
230
136
132
135b
138b
134a
131b
131
131a
138b
HZ2
HZ1
235
235a
135a
133
138a
X
Y'
Z'

FIG. 9

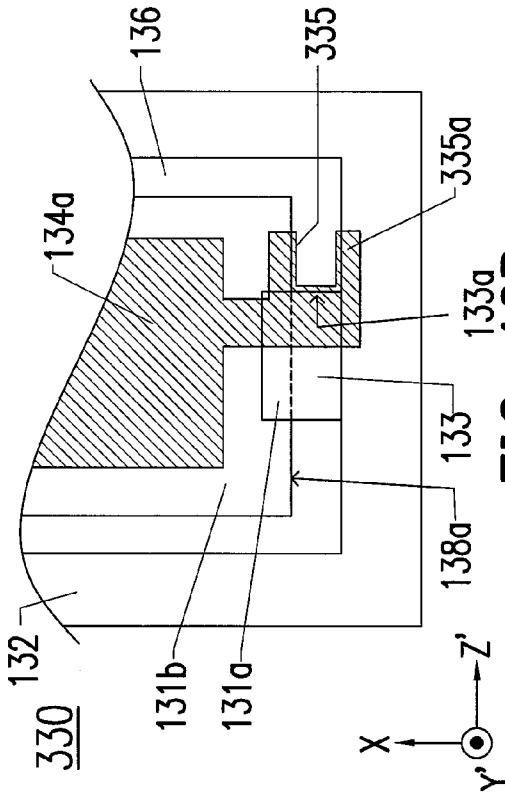

FIG. 10B

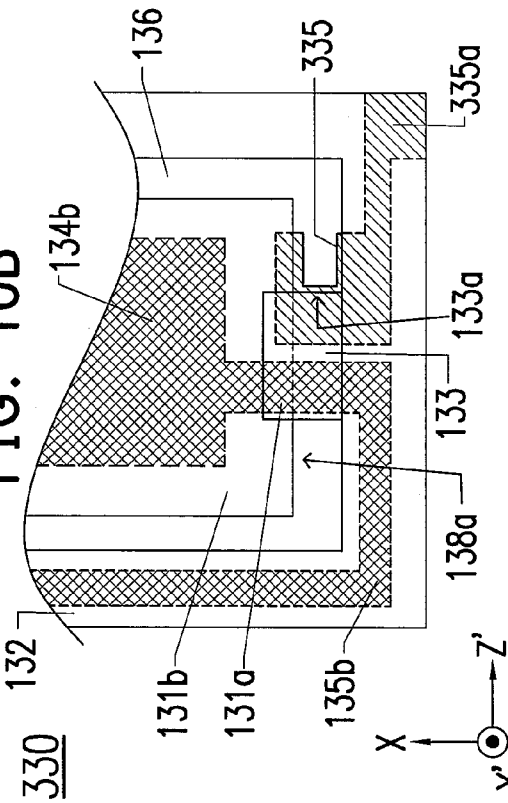

FIG. 10C

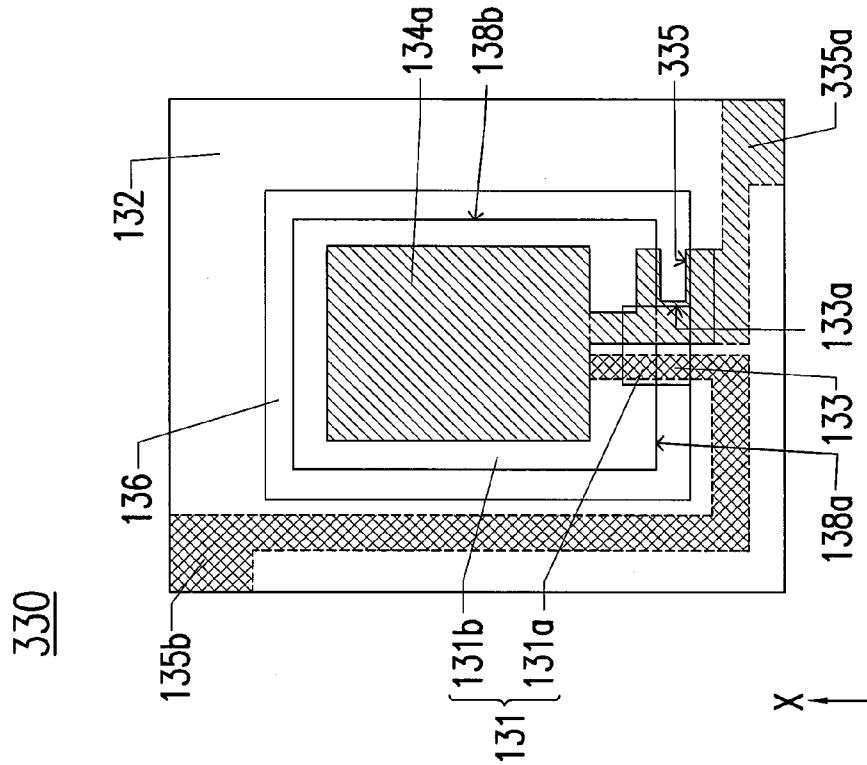

FIG. 10A

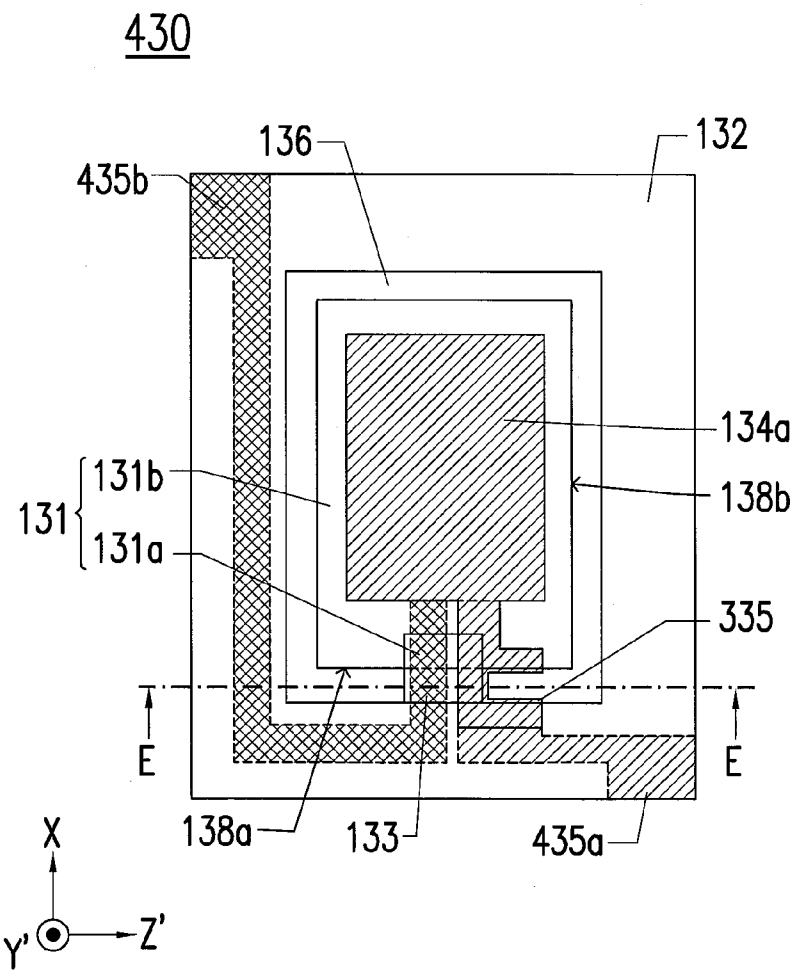

FIG. 11A

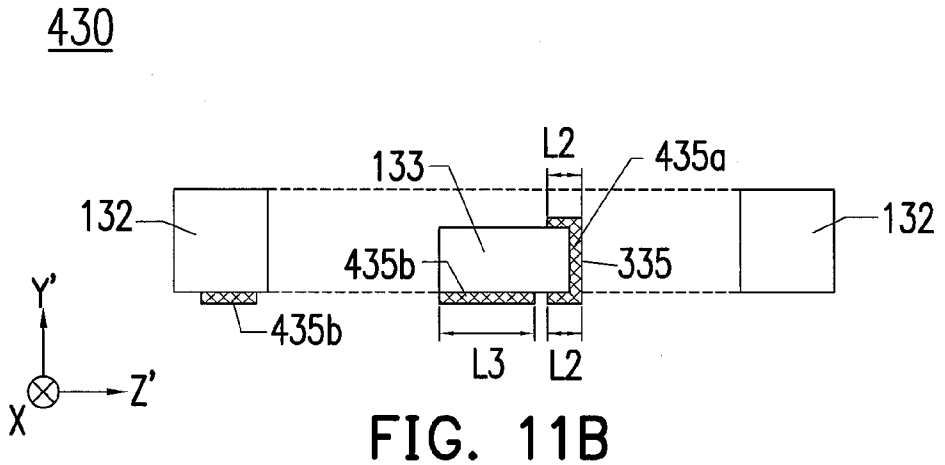

FIG. 11B

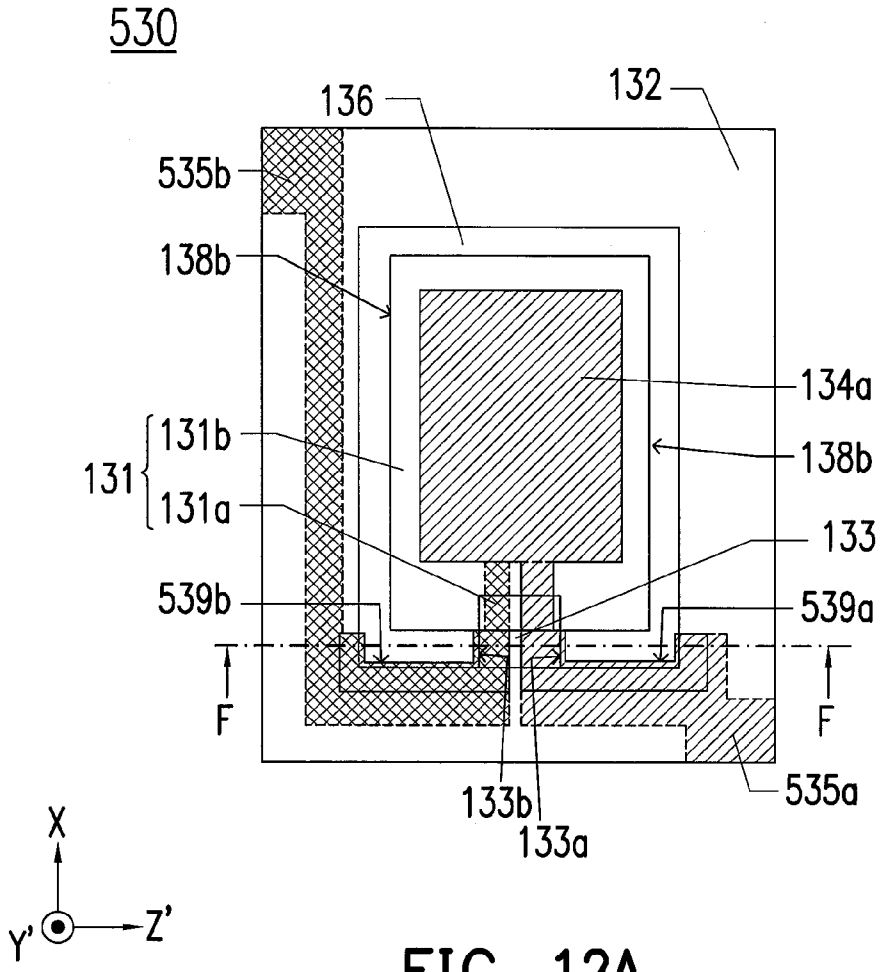

FIG. 12A

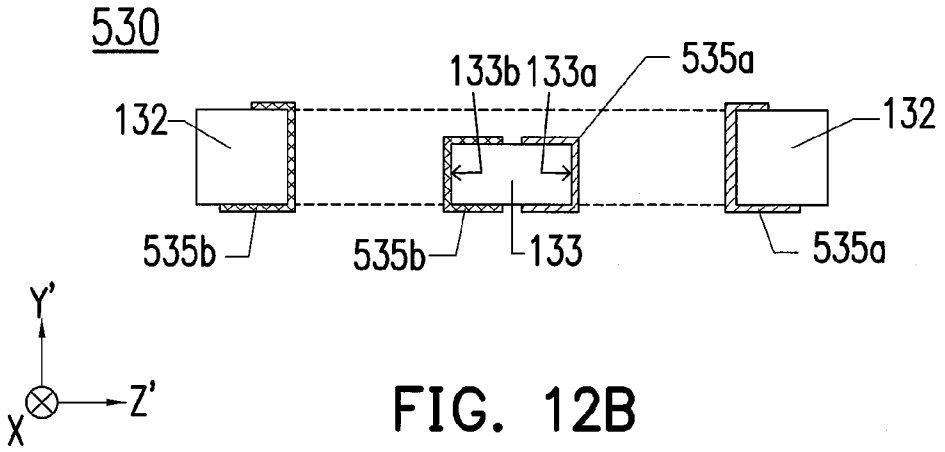

FIG. 12B

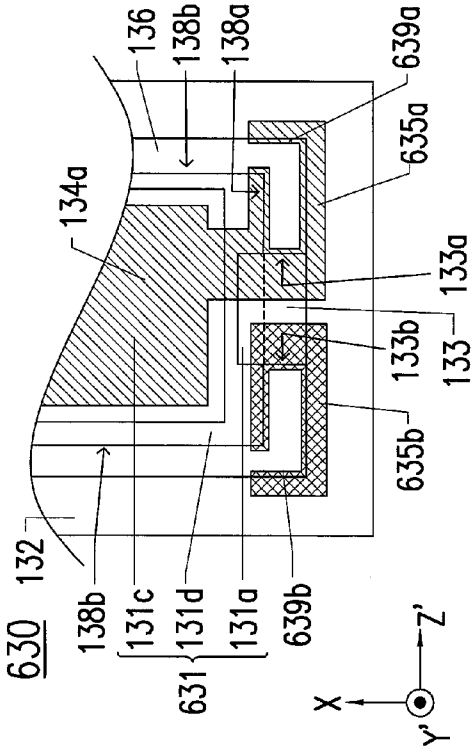

FIG. 13C

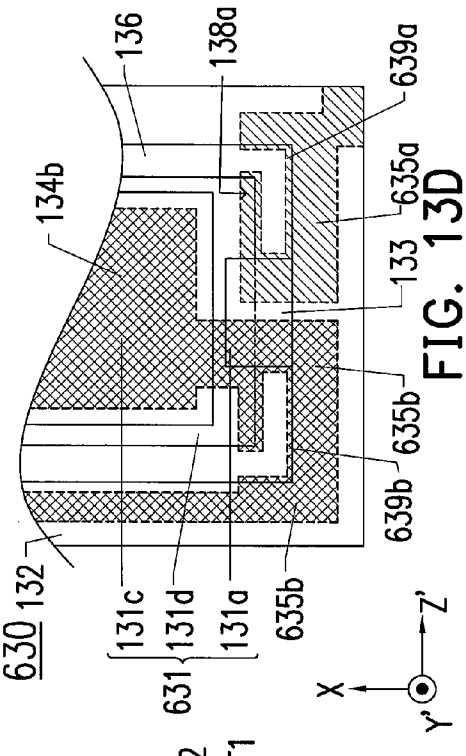

FIG. 13D

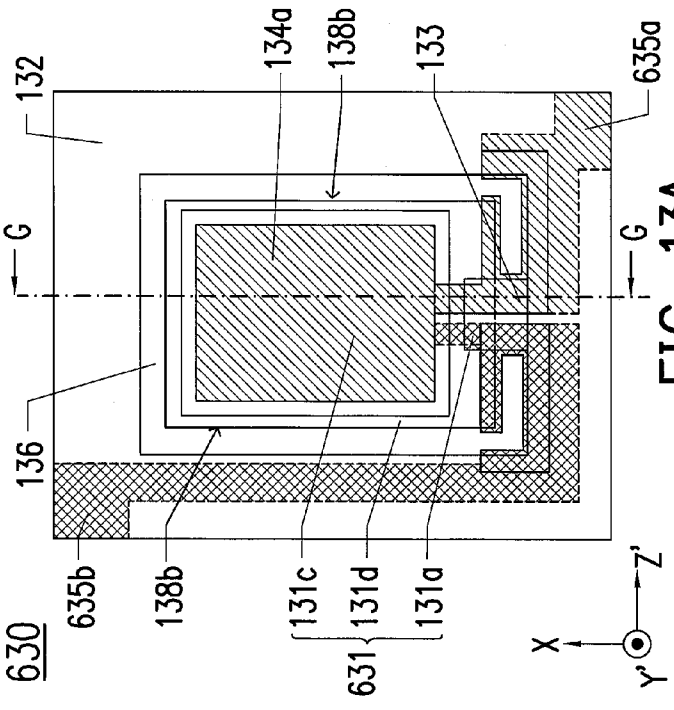

FIG. 13A

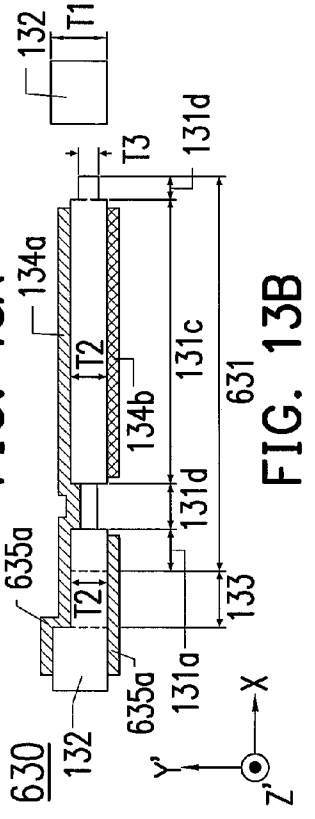

FIG. 13B

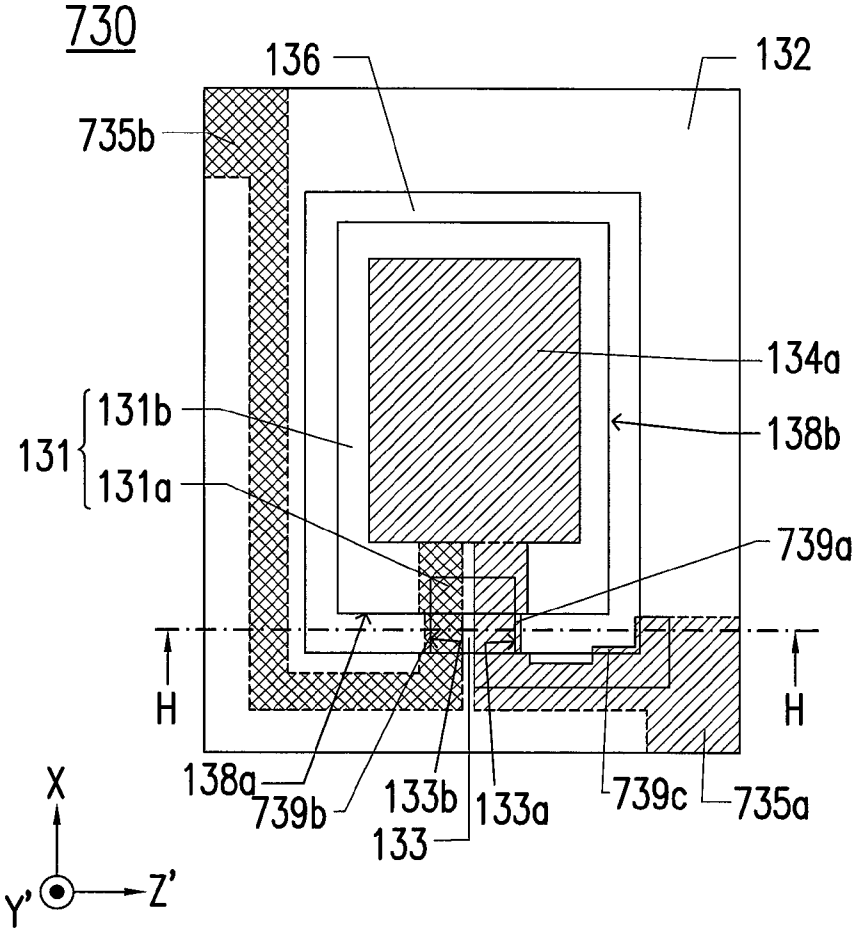

FIG. 14A

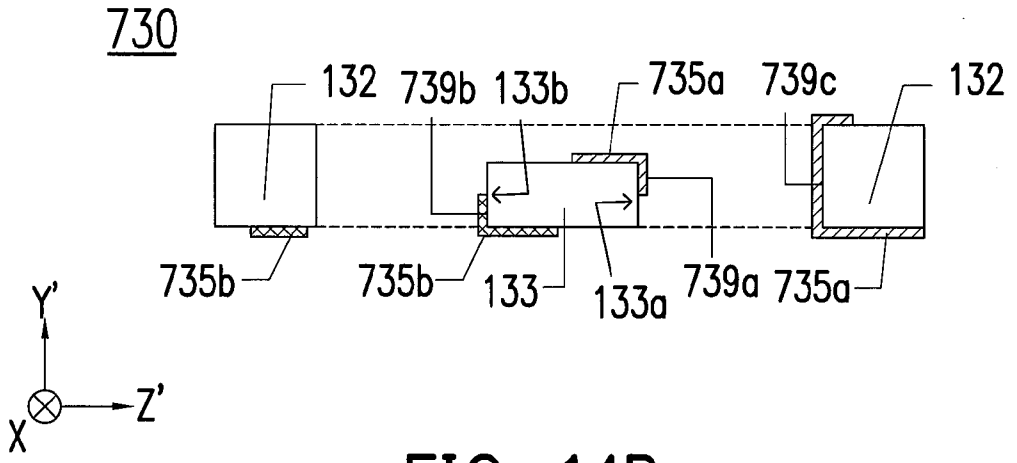

FIG. 14B

PIEZOELECTRIC VIBRATING PIECE, PIEZOELECTRIC DEVICE, AND METHOD FOR MANUFACTURING PIEZOELECTRIC DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit of Japan application serial no. 2011-159494, filed on Jul. 21, 2011. The entirety of the above-mentioned patent application is hereby incorporated by reference herein and made a part of this specification.

FIELD

[0002] This disclosure relates to piezoelectric vibrating pieces and piezoelectric devices that include extraction electrodes with large areas on connecting portions, and methods for manufacturing such piezoelectric devices.

DESCRIPTION OF THE RELATED ART

[0003] A known piezoelectric vibrating piece includes an excitation unit that vibrates at a predetermined vibration frequency. The piezoelectric vibrating piece is secured and supported by, for example, a supporting member inside a package, thus forming a piezoelectric device. The piezoelectric device is used to be mounted on, for example, a printed circuit board. The piezoelectric vibrating piece has a problem in that a vibration characteristic is changed by stress such as strain generated when the piezoelectric vibrating piece is packaged.

[0004] To solve this problem, for example, Japanese Unexamined Patent Application Publication No. 5-226963 proposes a piezoelectric resonator piece that includes a slit. The slit is formed by hollowing out an outer periphery of a vibrator that generates main vibration. That is, the piezoelectric resonator piece disclosed in this publication includes the vibrator, an end portion, and one connecting portion, which connects the vibrator and the end portion. The end portion surrounds the vibrator. The end portion is secured to and supported by a package with, for example, a supporting member. In this piezoelectric resonator piece disclosed in the publication, a portion supported by the supporting member and the vibrator are mechanically separated. This prevents transmission of strain or the like, which is generated when the piezoelectric vibrating piece is packaged, to the vibrator.

[0005] In addition to the strain or the like, which is generated when the piezoelectric vibrating piece is packaged, bending stress applied to a printed circuit board is transmitted to the piezoelectric vibrating piece. Thus, the piezoelectric vibrating piece possibly undergoes the stresses at all times while the piezoelectric device is mounted on a printed circuit board. Forming one connecting portion with a narrow width reduces transmission of these stresses to the vibrator. In this case, a problem arises in that this thin connecting portion provides a small area, for forming extraction electrodes at the connecting portion, thus increasing electrical resistance of the extraction electrode. This in turn increases a crystal impedance (CI) value of the piezoelectric vibrating piece.

[0006] Therefore, there is a need for a piezoelectric vibrating piece and a piezoelectric device, as disclosed herein, that includes extraction electrodes with large areas on a connecting portion. There is also a need for a method for manufacturing the piezoelectric device.

SUMMARY

[0007] A first aspect of a piezoelectric vibrating piece is to be bonded to and sandwiched between a lid plate and a base plate with an external electrode. The piezoelectric vibrating piece has a first main surface at the lid plate side and a second main surface at the base plate side. The piezoelectric vibrating piece includes an excitation unit in a rectangular shape, a first excitation electrode, a second excitation electrode, a framing portion, one connecting portion, a first extraction electrode, and a second extraction electrode. The excitation unit includes a first side and a second side. The first side extends in a first direction. The second side extends in a second direction perpendicular to the first direction. The first excitation electrode is on the first main surface of the excitation unit. The second excitation electrode is on the second main surface of the excitation unit. The framing portion includes a first bonding surface and a second bonding surface. The first bonding surface is a surface to be bonded to the lid plate. The second bonding surface is a surface to be bonded to the base plate. The framing portion surrounds the excitation unit. The one connecting portion connects the first side of the excitation unit and the framing portion together. The one connecting portion includes a planar surface parallel to both the main surfaces and a side face intersecting with the planar surface. The first extraction electrode is extracted from the first excitation electrode to the second bonding surface of the framing portion via the connecting portion. The second extraction electrode is extracted from the second excitation electrode to the second bonding surface of the framing portion via the connecting portion. The first extraction electrode is disposed on at least a part of the side face of the connecting portion to be extracted to the framing portion.

[0008] In the first aspect, a second aspect of a piezoelectric vibrating piece includes the first extraction electrode and the second extraction electrode that do not overlap with one another in a confronting direction of the planar surfaces or in a confronting direction of the side faces.

[0009] In the second aspect, a third aspect is directed to a piezoelectric vibrating piece where the first extraction electrode is disposed on the side face of the connecting portion, the first main surface, and the second main surface, and the second extraction electrode is disposed only on the second main surface of the connecting portion.

[0010] In the third aspect, a fourth aspect is directed to a piezoelectric vibrating piece where a width of the first extraction electrode on the second main surface of the connecting portion in the confronting direction of the side faces is smaller than a width of the second extraction electrode on the second main surface of the connecting portion in the confronting direction of the side faces.

[0011] In any one of the first aspect to the third aspect, a fifth aspect is directed to a piezoelectric vibrating piece where the first extraction electrode has a first length extracted from one end of the first excitation electrode side to another end, the other end extending to the second bonding surface, the second extraction electrode has a second length extracted from one end of the second excitation electrode side to another end, the other end extending to the second bonding surface, the first length is shorter than the second length, the first excitation electrode is thinner than the second excitation electrode, and a part of the first extraction electrode is thinner than the second extraction electrode.

[0012] In any one of the first aspect to the fifth aspect, a sixth aspect is directed to a piezoelectric vibrating piece

where the first extraction electrode is disposed on the first bonding surface of the framing portion, and a total area of the first extraction electrode and the second extraction electrode at the lid plate side of the connecting portion is smaller than a total area of the first extraction electrode and the second extraction electrode at the base plate side of the connecting portion.

[0013] In any one of the first aspect to the sixth aspect, a seventh aspect is directed to a piezoelectric vibrating piece where the first extraction electrode is disposed on a side face of the first side of the excitation unit.

[0014] In the seventh aspect, an eighth aspect is directed to a piezoelectric vibrating piece where the first extraction electrode is disposed on a side face of the framing portion. The side face intersects with both the bonding surfaces.

[0015] In the fifth aspect, a ninth aspect is directed to a piezoelectric vibrating piece where a width of a portion of the first extraction electrode where the first extraction electrode connects the first excitation electrode is larger than a width of a portion of the second extraction electrode where the second excitation electrode connects the second extraction electrode.

[0016] In any one of the first aspect to the ninth aspect, a tenth aspect is directed to a piezoelectric vibrating piece where the connecting portion has a first thickness in the confronting direction of the planar surfaces. The excitation unit includes a first region and a second region. The first region includes at least a part of the first side. The first region with the first thickness is directly connected to the connecting portion in the confronting direction of the planar surfaces. The second region is other than the first region where the first and the second excitation electrodes are disposed. A thickness of the second region in the confronting direction of the planar surfaces is thinner than a thickness of the first region in the confronting direction of the planar surfaces.

[0017] In any one of the first aspect to the ninth aspect, an eleventh aspect is directed to a piezoelectric vibrating piece where the connecting portion has a first thickness in the confronting direction of the planar surfaces. The excitation unit includes a first region, a third region, and a fourth region. The first region includes at least a part of the first side. The first region with the first thickness is directly connected to the connecting portion in the confronting direction of the planar surfaces. The third region has a second thickness in the confronting direction of the planar surfaces. The first and the second excitation electrodes are disposed on the third region. The fourth region is other than the first region and the third region. The fourth region has a third thickness in the confronting direction of the planar surfaces. The fourth region is disposed between the first region and the third region. The first thickness and the second thickness are thicker than the third thickness.

[0018] A twelfth aspect is directed to a piezoelectric device that includes the piezoelectric vibrating piece according to any one of the first aspect to the eleventh aspect, the lid plate, and the base plate. The piezoelectric vibrating piece is sandwiched between the lid plate and the base plate.

[0019] A thirteenth aspect is directed to a method for manufacturing a piezoelectric device. The method includes forming outlines, forming electrodes, preparing lid wafer, preparing base wafer, bonding second main surface, adjusting vibration frequency, and bonding first main surface. The forming outlines forms outlines of a plurality of piezoelectric vibrating pieces on a piezoelectric wafer. The piezoelectric wafer has a first main surface and a second main surface. The piezoelectric wafer includes a piezoelectric material. The piezoelectric vibrating piece includes an excitation unit, a framing portion, and one connecting portion. The excitation unit is configured to vibrate at a predetermined vibration frequency. The framing portion surrounds the excitation unit. The one connecting portion connects the excitation unit and the framing portion together. The forming electrodes forms electrodes. The electrodes includes a first excitation electrode and a second excitation electrode, a first extraction electrode, and a second extraction electrode. The first excitation electrode and the second excitation electrode are respectively disposed on the first main surface and the second main surface of the excitation unit. The first extraction electrode has a first length extracted from one end of the first excitation electrode side to another end of the second bonding surface of the framing portion via the connecting portion. The first extraction electrode is disposed on at least a part of a side face of the connecting portion. The second extraction electrode has a second length extracted from one end of the second excitation electrode side to another end of the second bonding surface of the framing portion via the connecting portion. The second length is longer than the first length. The preparing lid wafer prepares a lid wafer including a plurality of lid plates. The preparing base wafer prepares a base wafer including a plurality of base plates. The bonding second main surface bonds the second main surface of the piezoelectric wafer to the base wafer via the sealing material. The adjusting vibration frequency adjusts vibration frequency of the excitation unit by reverse sputtering on the first excitation electrode. The first excitation electrode is disposed on the first main surface of the piezoelectric wafer. The bonding first main surface bonds the first main surface of the piezoelectric wafer to the lid wafer via the sealing material.

[0020] With the piezoelectric vibrating piece, the piezoelectric device, and the method for manufacturing the piezoelectric device of the present invention, the extraction electrodes with large areas are formed on the connecting portion. This prevents the CI value from increasing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] FIG. **1** is an exploded perspective view of a piezoelectric device **100** according to a first embodiment.

[0022] FIG. **2** is a cross-sectional view taken along the line A-A of FIG. **1**.

[0023] FIG. **3**A is a plan view of a piezoelectric vibrating piece **130**.

[0024] FIG. **3**B is a cross-sectional view taken along the line B-B of FIG. **3**A.

[0025] FIG. **4**A is a plan view of the piezoelectric vibrating piece **130** without electrodes.

[0026] FIG. **4**B is a cross-sectional view taken along the line C-C of FIG. **3**A.

[0027] FIG. **5** is a flowchart illustrating a method for manufacturing the piezoelectric device **100**.

[0028] FIG. **6**A is a plan view of a piezoelectric wafer W**130** with outlines of the piezoelectric vibrating pieces **130**.

[0029] FIG. **6**B is a plan view of the piezoelectric wafer W**130** with electrodes.

[0030] FIG. **7**A is a plan view of a base wafer W**120**.

[0031] FIG. **7**B is a plan view of a lid wafer W**110**.

[0032] FIG. **8**A is a partial cross-sectional view of the piezoelectric wafer W**130** and the base wafer W**120**.

[0033] FIG. **8**B is a partial cross-sectional view of the piezoelectric wafer W**130** on which reverse sputtering is performed and the base wafer W**120**.

[0034] FIG. **8**C is a partial cross-sectional view of the piezoelectric wafer W**130**, the lid wafer W**110**, and the base wafer W**120**.

[0035] FIG. **9** is a plan view of a piezoelectric vibrating piece **230** according to a second embodiment.

[0036] FIG. **10**A is a plan view of a piezoelectric vibrating piece **330** according to a third embodiment.

[0037] FIG. **10**B is a partial plan view of the piezoelectric vibrating piece **330** illustrating electrodes on a surface at the +Y' axis side.

[0038] FIG. **10**C is a partial plan view of the piezoelectric vibrating piece **330** illustrating electrodes on a surface at the −Y' axis side.

[0039] FIG. **11**A is a plan view of a piezoelectric vibrating piece **430**.

[0040] FIG. **11**B is a cross-sectional view taken along the line E-E of FIG. **11**A.

[0041] FIG. **12**A is a plan view of a piezoelectric vibrating piece **530**.

[0042] FIG. **12**B is a cross-sectional view taken along the line F-F of FIG. **12**A.

[0043] FIG. **13**A is a plan view of a piezoelectric vibrating piece **630**.

[0044] FIG. **13**B is a cross-sectional view taken along the line G-G of FIG. **13**A.

[0045] FIG. **13**C is a partial plan view of the piezoelectric vibrating piece **630** illustrating electrodes on a surface at the +Y' axis side.

[0046] FIG. **13**D is a partial plan view of the piezoelectric vibrating piece **630** illustrating electrodes on a surface at the −Y' axis side.

[0047] FIG. **14**A is a plan view of a piezoelectric vibrating piece **730**.

[0048] FIG. **14**B is a cross-sectional view taken along the line H-H of FIG. **14**A.

DETAILED DESCRIPTION

[0049] Each embodiment of the present invention is described below by referring to the accompanying drawings. It will be understood that the scope of the disclosure is not limited to the described embodiments, unless otherwise stated.

Configuration of a Piezoelectric Device **100** According to a First Embodiment

[0050] FIG. **1** is an exploded perspective view of the piezoelectric device **100**. The piezoelectric device **100** includes a lid plate **110**, a base plate **120**, and a piezoelectric vibrating piece **130**. The piezoelectric vibrating piece **130** employs, for example, an AT-cut quartz-crystal vibrating piece. The AT-cut quartz-crystal vibrating piece has a principal surface (in the Y−Z plane) that is tilted by 35° 15' about the Y-axis of the crystal coordinate system (XYZ) in the direction from the Z-axis to the Y-axis around the X-axis. In the following description, the new axises tilted with reference to the axis directions of the AT-cut quartz-crystal vibrating piece are denoted as the Y' axis and the Z' axis. Therefore, in description of the piezoelectric device **100**, the longitudinal direction of the piezoelectric device **100** is referred as the X axis direction, the height direction of the piezoelectric device **100** is referred as the Y' axis direction, and the direction perpendicular to the X axis and Y' axis directions is referred as the Z' axis direction.

[0051] The piezoelectric vibrating piece **130** includes an excitation unit **131**, which vibrates at a predetermined vibration frequency and is formed in a rectangular shape, a framing portion **132**, which surrounds the excitation unit **131**, and one connecting portion **133**, which connects the excitation unit **131** and the framing portion **132** together. Regions other than the connecting portion **133** between the excitation unit **131** and the framing portion **132** constitutes a through-hole **136** that passes through the piezoelectric vibrating piece **130** in the Y' axis direction. The piezoelectric vibrating piece **130** is bonded to the lid plate **110** at its first bonding surface **132***a*, which is a surface at the +Y' axis side of the framing portion **132**. The piezoelectric vibrating piece **130** is bonded to the base plate **120** at its second bonding surface **132***b*, which is a surface at the −Y' axis side of the framing portion **132**. A first excitation electrode **134***a* is formed on a surface at the +Y' axis side of the excitation unit **131**, while a second excitation electrode **134***b* is formed on a surface at the −Y' axis side of the excitation unit **131**. A first extraction electrode **135***a* is extracted from the first excitation electrode **134***a* to the second bonding surface **132***b* of the framing portion **132** via a side face **133***a* at the +Z' axis side of the connecting portion **133**. A second extraction electrode **135***b* is extracted from the second excitation electrode **134***b* to the second bonding surface **132***b* of the framing portion **132** via a surface at the −Y' axis side of the connecting portion **133**.

[0052] The base plate **120** is arranged at the −Y' axis side of the piezoelectric vibrating piece **130**. The base plate **120** is formed in a rectangular shape that has long sides in the X axis direction and short sides in the Z' axis direction. A pair of mounting terminals **124** are formed on a surface at the −Y' axis side of the base plate **120**. The mounting terminals **124** are soldered and electrically connected to a printed circuit board or the like, by doing this, the piezoelectric device **100** is mounted on the printed circuit board or the like. Castellations **126** are formed on side faces at four corners of the base plate **120**. Castellation electrodes **125** are formed at the respective castellations **126**. A recess **121** is formed on a surface at the +Y' axis side of the base plate **120**. A bonding surface **122** is formed in a peripheral area of the recess **121**. Connecting electrodes **123** are formed on peripheral areas of the respective castellations **126** at the four corners of the bonding surface **122**. These connecting electrodes **123** are electrically connected to the mounting terminals **124** via the castellation electrodes **125**, which are formed on the castellations **126**. The base plate **120** is bonded on the second bonding surface **132***b* of the framing portion **132** in the piezoelectric vibrating piece **130** via a sealing material **141** (see FIG. **2**) at its bonding surface **122**. The connecting electrodes **123** are electrically connected to the first extraction electrode **135***a* and the second extraction electrode **135***b* of the piezoelectric vibrating piece **130**.

[0053] The lid plate **110** is arranged at the +Y' axis side of the piezoelectric vibrating piece **130**. A recess **111** is formed on a surface at the −Y' axis side of the lid plate **110**, and a bonding surface **112** is formed in a peripheral area of the recess **111**. The lid plate **110** is bonded to the first bonding surface **132***a* of the framing portion **132** in the piezoelectric vibrating piece **130** via the sealing material **141** (see FIG. **2**) at its bonding surface **112**.

[0054] FIG. **2** is a cross-sectional view taken along the line A-A of FIG. **1**. In the piezoelectric device **100**, the bonding surface **112** of the lid plate **110** is bonded to the first bonding surface **132***a* of the framing portion **132** in the piezoelectric vibrating piece **130** via the sealing material **141**. In the piezoelectric device **100**, the bonding surface **122** of the base plate **120** is bonded to the second bonding surface **132***b* of the framing portion **132** via the sealing material **141**. When the piezoelectric vibrating piece **130** and the base plate **120** are bonded together, the first extraction electrode **135***a* and the second extraction electrode **135***b*, which are formed on the second bonding surface **132***b* of the framing portion **132**, are electrically connected to the connecting electrodes **123**, which are formed on the bonding surface **122** of the base plate **120**. Accordingly, the first excitation electrode **134***a* is electrically connected to the mounting terminals **124** via the first extraction electrode **135***a*, the connecting electrodes **123**, and the castellation electrodes **125**, while the second excitation electrode **134***b* is electrically connected to the mounting terminals **124** via the second extraction electrode **135***b*, the connecting electrodes **123**, and the castellation electrodes **125**.

[0055] FIG. **3**A is a plan view of the piezoelectric vibrating piece **130**. The piezoelectric vibrating piece **130** includes the excitation unit **131** formed in a rectangular shape, the framing portion **132**, which surrounds the excitation unit **131**, and the one connecting portion **133**, which connects the excitation unit **131** and the framing portion **132** together. The excitation unit **131** includes a first side **138***a* and second sides **138***b*. The first side **138***a* is the short side of the excitation unit **131** at the −X axis side of the excitation unit **131**. The second sides **138***b* are long sides of the excitation unit **131** at the +Z' axis side and the −Z' axis side of the excitation unit **131**. The connecting portion **133** is connected to the center of the first side **138***a* of the excitation unit **131**, and extends in the −X axis direction so as to connect to the framing portion **132**. And, regions other than the connecting portion **133** between the excitation unit **131** and the framing portion **132** constitute the through-hole **136** that passes through the piezoelectric vibrating piece **130** in the Y' axis direction. The excitation unit **131** is separated into a first region **131***a* and a second region **131***b*. The first region **131***a* is a region that is directly connected to the connecting portion **133**. The second region **131***b* is a region other than the first region **131***a* on which the first excitation electrode **134***a* and the second excitation electrode **134***b* are formed. In the piezoelectric vibrating piece **130**, the first region **131***a* is formed thicker than the second region **131***b* in the Y' axis direction. The first excitation electrode **134***a* is formed on the surface at the +Y' axis side of the excitation unit **131**. The first extraction electrode **135***a* is extracted from the first excitation electrode **134***a* to a corner portion at the −X axis side and the +Z' axis side on the surface at the −Y' axis side of the framing portion **132** via the first region **131***a*, a surface at the +Y' axis side of the connecting portion **133**, the side face **133***a* at the +Z' axis side of the connecting portion **133**, and a surface at the −Y' axis side of the connecting portion **133**. And, the second excitation electrode **134***b* (see FIG. **2**) is formed on the surface at the −Y' axis side of the excitation unit **131**. The second extraction electrode **135***b* is extracted from the second excitation electrode **134***b* to the framing portion **132** via a surface of the first region **131***a* and a surface of the connecting portion **133** at the −Y' axis side. The second extraction electrode **135***b* further extends on a surface at the −Y' axis side of the framing portion **132** in the −Z' axis direction and then in the +X axis direction. The second extraction electrode **135***b* is then extracted to a corner portion at the +X axis side and the −Z' axis side on a surface at the −Y' axis side of the framing portion **132**. Since the second extraction electrode **135***b* is extracted to the +X axis side of the framing portion **132**, the second extraction electrode **135***b* is formed longer than the first extraction electrode **135***a*.

[0056] FIG. **3**B is a cross-sectional view taken along the line B-B of FIG. **3**A. FIG. **3**B illustrates a cross-sectional view of the framing portion **132** and the connecting portion **133** in the Y'−Z' the plane. The first extraction electrode **135***a* extends from the first excitation electrode **134***a*, which is formed at the +Y' axis side of the excitation unit **131**. The first extraction electrode **135***a* is extracted from the surface at the +Y' axis side of the connecting portion **133** to the surface at the −Y' axis side of the connecting portion **133** via the side face **133***a*. Widths of the first extraction electrode **135***a* in the Z' axis direction on respective surfaces at the +Y' axis side and at the −Y' axis side of the connecting portion **133** are formed to be a width L**1**. The second extraction electrode **135***b* extends from the second excitation electrode **134***b*, which is formed on the surface at the −Y' axis side of the excitation unit **131**. The second extraction electrode **135***b* is extracted from the excitation unit **131** to the framing portion **132** via the surface at the −Y' axis side of the connecting portion **133**. The second extraction electrode **135***b* is formed to have the width L**1** in the Z' axis direction on the connecting portion **133**. Assume that a width of the connecting portion **133** in the Z' axis direction is a width RZ**1**, the width RZ**1** is larger than double of the width L**1**. The first extraction electrode **135***a* and the second extraction electrode **135***b* are formed on the connecting portion **133**, so as not to face one another in the Z' axis direction or the Y' axis direction.

[0057] FIG. **4**A is a plan view of the piezoelectric vibrating piece **130** on which electrodes are not formed. FIG. **4**A illustrates a region on which the first excitation electrode **134***a* is formed as a reference. This region is surrounded by a dotted line. The first side **138***a* of the excitation unit **131** is formed to have a length LZ**1**, while the second side **138***b* is formed to have a length LX**1**. In the piezoelectric vibrating piece **130**, the first side **138***a* is the short side of the excitation unit **131**, while the second side **138***b* is the long side of the excitation unit **131**. Thus, the length LZ**1** is shorter than the length LX**1**. Assume that a whole length of the framing portion **132** in the X axis direction in the piezoelectric vibrating piece **130** is a length WX**1**, a whole length of the framing portion **132** in the Z' axis direction is a length WZ**1**, a length in the X axis direction of the framing portion **132** that extends in the Z' axis direction is a length WX**2**, and a length in the Z' axis direction of the framing portion **132** that extends in the X axis direction is a length WZ**2**. In the piezoelectric vibrating piece **130**, for example, the respective lengths are as follows. The length LZ**1** is 1.0 mm, the length LX**1** is 1.4 mm, the length WX**1** is 2.0 mm, the length WX**2** is 0.2 mm, the length WZ**1** is 1.6 mm, and the length WZ**2** is 0.2 mm. Assume that a length in the Z' axis direction of the connecting portion **133** in the piezoelectric vibrating piece **130** is a width RZ**1**, the piezoelectric vibrating piece **130** is formed such that, for example, the width RZ**1** is 0.2 mm.

[0058] FIG. **4**B is a cross-sectional view taken along the line C-C of FIG. **3**A. The piezoelectric vibrating piece **130** is formed such that the framing portion **132** has a thickness of T**1** in the Y' axis direction, the connecting portion **133** and the

first region **131***a* of the excitation unit **131** have a thickness of T**2** in the Y' axis direction, and the second region **131***b* of the excitation unit **131** has a thickness of T**3** in the Y' axis direction. In the piezoelectric vibrating piece **130**, the thickness T**1** is formed to be thicker than the thickness T**3**, while the thickness T**2** is equal to or less than the thickness T**1** and larger than the thickness T**3**. Thus, the piezoelectric vibrating piece **130** is formed such that, for example, the thickness T**1** is 80 μm, the thickness T**2** is 70 μM, and the thickness T**3** is 40 μm.

[0059] In the piezoelectric vibrating piece **130**, as illustrated in FIG. **3**B, the first extraction electrode **135***a* and the second extraction electrode **135***b* are formed on the connecting portion **133**, so as not to face one another in the Y' and Z' axis directions. This reduces capacitance in the connecting portion **133** and avoids increase in crystal impedance (CI) value of the piezoelectric vibrating piece **130**.

A Method for Manufacturing the Piezoelectric Device **100**

[0060] A method for manufacturing the piezoelectric device **100** will be described by referring to a flowchart in FIG. **5**.

[0061] FIG. **5** is a flowchart illustrating the method for manufacturing the piezoelectric device **100**. In step S**101**, outlines of a plurality of piezoelectric vibrating pieces **130** are formed on a piezoelectric wafer W**130**. The piezoelectric wafer W**130** is made of piezoelectric material. The outlines of the piezoelectric vibrating pieces **130** are formed as follows. First, a metal layer and a photoresist are formed on the piezoelectric wafer W**130**. Next, the photoresist is exposed and developed, and the metal layer is removed, thus exposing a part of the piezoelectric wafer W**130**. Then, the exposed regions of the piezoelectric wafer W**130** are etched.

[0062] FIG. **6**A is a plan view of the piezoelectric wafer W**130** on which the outlines of the piezoelectric vibrating pieces **130** are formed. On the piezoelectric wafer W**130**, outlines of the plurality of piezoelectric vibrating pieces **130** are formed. On the piezoelectric wafer W**130** illustrated in FIG. **6**A, scribe lines **142** are illustrated by two-dot chain lines. The wafer is cut along the scribe lines **142** to dice the wafer in step S**108** as described later. Each piezoelectric vibrating piece **130**, which is illustrated on the piezoelectric wafer W**130**, is surrounded by the scribe lines **142**. In the piezoelectric wafer W**130** illustrated in FIG. **6**A, the excitation unit **131**, the connecting portion **133**, and the through-hole **136** are formed by etching the piezoelectric wafer W**130**.

[0063] In step S**102**, electrodes are formed on the piezoelectric wafer W**130**. In step S**102**, the first excitation electrode **134***a*, the second excitation electrode **134***b*, the first extraction electrode **135***a*, and the second extraction electrode **135***b* are formed on each of the piezoelectric vibrating pieces **130** formed on the piezoelectric wafer W**130**. These electrodes are formed, for example, by forming a chromium (Cr) layer on the piezoelectric wafer W**130** and evaporating a gold (Au) layer on a surface of the chromium layer.

[0064] FIG. **6**B is a plan view of the piezoelectric wafer W**130** on which the electrodes are formed. FIG. **6**B illustrates the piezoelectric vibrating pieces **130** that each have the first excitation electrode **134***a*, the first extraction electrode **135***a*, and the second extraction electrode **135***b*. These electrodes are formed by evaporating the chromium (Cr) layer and the gold (Au) layer on surfaces at the +Y' axis side and the −Y' axis side of the piezoelectric wafer W**130** via a mask (not shown).

[0065] In step S**103**, a base wafer W**120** is prepared. A plurality of base plates **120** are formed on the base wafer W**120**. On the base wafer W**120**, first, the recesses **121** and through grooves **126***a*, which forms the castellations **126** later, (see FIG. **7**A) are formed by etching. Then electrodes such as the connecting electrodes **123**, the castellation electrodes **125**, and the mounting terminals **124** are formed.

[0066] FIG. **7**A is a plan view of the base wafer W**120**. In FIG. **7**A, the scribe lines **142** are illustrated by two-dot chain lines. The respective base plates **120**, which are formed on the base wafer W**120**, are surrounded by the scribe lines **142**. Moreover, the scribe lines **142** that extend in the X axis direction of the base wafer W**120** and the scribe lines **142** that extend in the Z' axis direction form intersection points. At the respective intersection points, the through grooves **126***a* are formed. The through grooves **126***a* pass through the base wafer W**120** in the Y' axis direction and form the castellations **126** after the wafer is diced. On the base wafer W**120**, first, the recesses **121** and the through grooves **126***a* are formed by etching. Then, for example, the chromium layer and the gold layer form the mounting terminals **124**, the castellation electrodes **125**, which are formed on the through grooves **126***a*, and the connecting electrodes **123** on surfaces around the through grooves **126***a* at the +Y' axis side.

[0067] In step S**104**, a lid wafer W**110** is prepared. On the lid wafer W**110**, a plurality of lid plates **110** are formed. The respective lid plates **110** on the lid wafer W**110** are formed by forming the recess **111** using etching.

[0068] FIG. **7**B is a plan view of the lid wafer W**110**. In FIG. **7**B, two-dot chain lines represent the scribe lines **142**. The respective lid plates **110** on the lid wafer W**110** are surrounded by the scribe lines **142**. The respective lid plates **110** are formed by etching the recesses **111** on the surface at the −Y' axis side of the lid wafer W**110**.

[0069] In step S**105**, the piezoelectric wafer W**130** and the base wafer W**120** are bonded together. In step S**105**, for example, the sealing material **141** (see FIG. **8**A) is formed on the bonding surface **122** of the base wafer W**120**, and then the second bonding surface **132***b* of the piezoelectric wafer W**130** is bonded to the bonding surface **122** of the base wafer W**120**. At the same time, the first extraction electrode **135***a* and the second extraction electrode **135***b* are electrically connected to the connecting electrodes **123**.

[0070] FIG. **8**A is a partial cross-sectional view of the piezoelectric wafer W**130** and the base wafer W**120**. FIG. **8**A illustrates a cross-sectional view taken along the respective lines D-D of FIG. **6**B and FIG. **7**A. The bonding surface **122** of the base wafer W**120** and the second bonding surface **132***b* of the piezoelectric wafer W**130** are bonded together with the sealing material **141**. The first extraction electrode **135***a* and the second extraction electrode **135***b* of the piezoelectric wafer W**130** are electrically connected to the connecting electrodes **123** of the base wafer W**120**.

[0071] In step S**106**, a vibration frequency of the excitation unit **131** is adjusted. The vibration frequency of the excitation unit **131** is adjusted by reverse sputtering performed on the first excitation electrode **134***a*, which is formed on the surface at the +Y' axis side of the excitation unit **131**.

[0072] FIG. **8**B is a partial cross-sectional view of the piezoelectric wafer W**130** on which reverse sputtering is performed and the base wafer W**120**. FIG. **8**B illustrates a cross-sectional view taken along the respective lines D-D of FIG. **6**B and FIG. **7**A. A vibration frequency of the excitation unit **131** is adjusted by reverse sputtering to thin the first excitation

electrode **134***a*, which is formed on the surface at the +Y' axis side of the excitation unit **131**. In reverse sputtering, regions other than the first excitation electrode **134***a* and its peripheral regions are covered with a mask **143**, and gas ions are then collided against the first excitation electrode **134***a* while a voltage is applied to the excitation unit **131**, so as to thin the first excitation electrode **134***a*. In FIG. **8**B, a direction of the gas ions colliding against the first excitation electrode **134***a* is illustrated by white arrows **144**. Assume that the first excitation electrode **134***a* has a thickness of RY**1** (see FIG. **8**A) before the reverse sputtering, and the first excitation electrode **134***a* of the excitation unit **131** has a thickness of RY**2** after the reverse sputtering. The thickness RY**2** is thinner than the thickness RY**1**. In the case where the first excitation electrode **134***a* before the reverse sputtering is formed to have the same thickness as that of the second excitation electrode **134***b*, the first excitation electrode **134***a* after the reverse sputtering has a thinner thickness than a thickness of the second excitation electrode **134***b*. Further, if the first extraction electrode **135***a* before the reverse sputtering is formed to have the same thickness as that of the second extraction electrode **135***b*, the first extraction electrode **135***a* after the reverse sputtering may have a thinner thickness than that of the second extraction electrode **135***b* due to, for example, displacement of the mask **143**.

[0073] In step S**107**, the piezoelectric wafer W**130** and the lid wafer W**110** are bonded together. In step S**107**, for example, the sealing material **141** (see FIG. **8**C) is formed on the first bonding surface **132***a* of the piezoelectric wafer W**130**, and the first bonding surface **132***a* of the piezoelectric wafer W**130** is then bonded to the bonding surface **112** of the lid wafer W**110**.

[0074] FIG. **8**C is a partial cross-sectional view of the piezoelectric wafer W**130**, the lid wafer W**110**, and the base wafer W**120**. FIG. **8**C illustrates a cross-sectional view taken along the respective lines D-D of FIGS. **6**B, **7**A, and **7**B. The bonding surface **112** of the lid wafer W**110** and the first bonding surface **132***a* of the piezoelectric wafer W**130** are bonded together by the sealing material **141**. This forms a plurality of piezoelectric devices **100** in the piezoelectric wafer W**130**, the lid wafer W**110**, and the base wafer W**120** that are bonded together.

[0075] In step S**108**, the wafers are diced. In step S**108**, the piezoelectric wafer W**130**, the lid wafer W**110**, and the base wafer W**120** that are bonded together are diced along the scribe lines **142**. Accordingly, the wafer is diced into the individual piezoelectric devices **100**.

[0076] In the method for manufacturing the piezoelectric device **100** illustrated in the flowchart of FIG. **5**, the reverse sputtering is performed on the first excitation electrode **134***a* in step S**106**. In the reverse sputtering, the mask **143** is placed over the piezoelectric wafer W**130**, and the mask **143** has an opening in a wider range than that of the first excitation electrode **134***a* in consideration of the displacement. Thus, the extraction electrodes, which are formed at the +Y' axis side of the piezoelectric vibrating piece **130**, are possibly thinned by the reverse sputtering. In the piezoelectric vibrating piece **130**, the first extraction electrode **135***a* is formed at the +Y' axis side. The first extraction electrode **135***a* is formed to have a short length, which is extracted from the first excitation electrode **134***a* to the second bonding surface **132***b*, thus ensuring low total electrical resistance. This makes influence of increase in electrical resistance of the first extraction electrode **135***a* due to thinning by the reverse sputtering be small. And, for the first excitation electrode **134***a*, the first extraction electrode **135***a* is formed on the surfaces at the +Y' axis side and the −Y' axis side and the side face **133***a* of the connecting portion **133**. The reverse sputtering affects only a part of the first extraction electrode **135***a* that is formed on the surface at the +Y' axis side of the connecting portion **133**. Accordingly, the reverse sputtering does not affects parts of the first extraction electrode **135***a* that are formed on the surface at the −Y' axis side of the connecting portion **133** and the side face **133***a*. The second extraction electrode **135***b*, which has a long length from the second excitation electrode **134***b* to the second bonding surface **132***b*, has higher electrical resistance than that of the first extraction electrode **135***a*. The second extraction electrode **135***b* is formed on the surface at the −Y' axis side of the piezoelectric vibrating piece **130**, thus being insusceptible to the reverse sputtering. This reduces influence of the reverse sputtering on the first extraction electrode **135***a* and the second extraction electrode **135***b* in the piezoelectric vibrating piece **130**, thus avoiding increase in crystal impedance (CI) value of the piezoelectric vibrating piece **130**.

Second Embodiment

[0077] The piezoelectric vibrating piece may have the first extraction electrode that is thinned by the reverse sputtering and has an increased electrical resistance. In particular, the first extraction electrode that is formed adjacent to the first excitation electrode may be thinned by the reverse sputtering. Thus, the first extraction electrode formed adjacent to the first excitation electrode may have a large area. A piezoelectric vibrating piece **230** that includes the first extraction electrode with a large area adjacent to the first excitation electrode will be described below. In the following description, like reference numerals designate corresponding or identical elements of the piezoelectric vibrating piece **130** in FIG. **9**, and therefore such elements will not be further elaborated here.

Configuration of the Piezoelectric Vibrating Piece **230**

[0078] FIG. **9** is a plan view of the piezoelectric vibrating piece **230**. The piezoelectric vibrating piece **230** includes the excitation unit **131**, the framing portion **132**, and the connecting portion **133**. In the piezoelectric vibrating piece **230**, the first excitation electrode **134***a* is formed on a surface at the +Y' axis side of the excitation unit **131**, and a first extraction electrode **235***a* is extracted from the first excitation electrode **134***a*. The first extraction electrode **235***a* is an extraction electrode, which is a combination of the first extraction electrode **135***a* (see FIG. **3**A) and an electrode **235**. The electrode **235** is an electrode on a surface at the +Y' axis side of the excitation unit **131**. The electrode **235** is formed at the +Z' axis side of the first extraction electrode **135***a*. The electrode **235** is formed in a region next to the first excitation electrode **134***a* and the first extraction electrode **135***a*. The electrode **235** is formed in a position that does not overlap with the second extraction electrode **135***b* in the Y' axis direction. A width HZ**1** is a width in the Z' axis direction of a portion where the first extraction electrode **235***a* and the first excitation electrode **134***a* are connected together. A width HZ**2** is a width in the Z' axis direction of a portion where the second extraction electrode **135***b* and the second excitation electrode **134***b* are connected together. The width HZ**1** is larger than the width HZ**2**.

[0079] In a piezoelectric vibrating piece, the reverse sputtering may thin a thickness of a first extraction electrode adjacent to a first excitation electrode, thus increasing electrical resistance of the first extraction electrode. In the piezoelectric vibrating piece **230**, since the first extraction electrode **235***a* includes the electrode **235**, the first extraction electrode **235***a* has a large area next to the first excitation electrode **134***a*. Thus, even if the thickness of the first extraction electrode **235***a* next to the first excitation electrode **134***a* is thinned by the reverse sputtering, the first extraction electrode **235***a* has a large area next to the first excitation electrode **134***a*. This avoids increase in electrical resistance of the first extraction electrode **235***a*.

Third Embodiment

[0080] In a piezoelectric vibrating piece, in the case where a first extraction electrode is extracted from a surface at the +Y' axis side to a surface at the −Y' axis side, the first extraction electrode passes through a side face of the piezoelectric vibrating piece. However, since it is difficult to form a thick electrode on the side face of the piezoelectric vibrating piece, the first extraction electrode may have an increased electrical resistance. Thus, the electrode on the side face of the piezoelectric vibrating piece may be formed to have a wide width. A piezoelectric vibrating piece that includes the first extraction electrode with a wide width on the side face of the piezoelectric vibrating piece will be described below.

Configuration of a Piezoelectric Vibrating Piece **330**

[0081] FIG. **10**A is a plan view of the piezoelectric vibrating piece **330**. The piezoelectric vibrating piece **330** includes the excitation unit **131**, the framing portion **132**, and the connecting portion **133**. And, in the excitation unit **131**, the first excitation electrode **134***a* and the second excitation electrode **134***b* are respectively formed on the surface at the +Y' axis side and the surface the −Y' axis side of the excitation unit **131**. A first extraction electrode **335***a* and the second extraction electrode **135***b* are respectively extracted from the first excitation electrode **134***a* and the second excitation electrode **134***b*. The first extraction electrode **335***a* includes a side-surface electrode **335**. The side-surface electrode **335** is an electrode that is formed on the side face **133***a* at the +Z' axis side of the connecting portion **133**, on a side face of the framing portion **132** intersecting with the side face **133***a*, and on a side face of the first side **138***a* intersecting with the side face **133***a*. The side-surface electrode **335** is formed on a side face of the through-hole **136** in the +Z' axis side of the connecting portion **133**.

[0082] FIG. **10**B is a partial plan view of the piezoelectric vibrating piece **330**, illustrating electrodes on a surface at the +Y' axis side. FIG. **10**B illustrates a half plan view of the piezoelectric vibrating piece **330** at the −X axis side. On the surface at the +Y' axis side, the first extraction electrode **335***a* is extracted from the first excitation electrode **134***a* to the side face **133***a* of the connecting portion **133**, the first side **138***a*, and a side face, which is connected to the connecting portion **133**, of the framing portion **132**. And, the first extraction electrode **335***a* is formed only on the half of the piezoelectric vibrating piece **330** at the +Z' axis side, so as not to overlap with the second extraction electrode **135***b* in the Y' axis direction. The first extraction electrode **335***a*, which is formed on the surface at the +Y' axis side, is electrically connected to the side-surface electrode **335** and extracted from the surface at the +Y' axis side to the surface at the −Y' axis side.

[0083] FIG. **10**C is a partial plan view of the piezoelectric vibrating piece **330**, illustrating electrodes on the surface at the −Y' axis side. FIG. **10**C illustrates a half plan view of the piezoelectric vibrating piece **330** at the −X axis side. On the surface at the −Y' axis side of the piezoelectric vibrating piece **330**, the first extraction electrode **335***a* is extracted from the side-surface electrode **335** to a corner portion at the −X axis side and the +Z' axis side of the framing portion **132**. The first extraction electrode **335***a* is extracted via the first side **138***a* of the excitation unit **131**, a side in contact with the side face **133***a* of the connecting portion **133**, a side that is connected to the connecting portion **133** in the framing portion **132**.

[0084] In the piezoelectric vibrating piece **330**, the first extraction electrode **335***a* is extracted from the surface at the +Y' axis side to the surface at the −Y' axis side via the side-surface electrode **335**. The side-surface electrode **335** is disposed on the side face **133***a* of the connecting portion **133**, the side face of the first side **138***a*, and the side face of the framing portion **132**. The side-surface electrode **335** has a long length in the X−Z' plane. That is, the side-surface electrode **335** is formed to have a large width, thus avoiding increase in electrical resistance of the first extraction electrode **335***a* caused by the reduced thickness of the side-surface electrode **335**. And, as illustrated in FIG. **10**B, the first extraction electrode **335***a*, which is formed on the surface at the +Y' axis side of the piezoelectric vibrating piece **330**, extends to the +Z' axis side of the piezoelectric vibrating piece **330**. Thus, verifying the first extraction electrode **335***a* on the surface at the +Y' axis side extends to either the +Z' axis direction or—the Z' axis direction allows to determine this surface of the piezoelectric vibrating piece **330** is either the surface at the +Y' axis side or the surface at the −Y' axis side.

Configuration of a Piezoelectric Vibrating Piece **430**

[0085] FIG. **11**A is a plan view of the piezoelectric vibrating piece **430**. The piezoelectric vibrating piece **430** includes the excitation unit **131**, the framing portion **132**, and the connecting portion **133**. In the excitation unit **131**, the first excitation electrode **134***a* and the second excitation electrode **134***b* are respectively formed on the surface at the +Y' axis side and the surface at the −Y' axis side of the excitation unit **131**. A first extraction electrode **435***a* and a second extraction electrode **435***b* are respectively extracted from the first excitation electrode **134***a* and the second excitation electrode **134***b*. The first extraction electrode **435***a* is extracted from the first excitation electrode **134***a* to a peripheral area of the side-surface electrode **335** on the surface at the +Y' axis side, and is then extracted to the surface at the −Y' axis side via the side-surface electrode **335**. Further, the first extraction electrode **435***a* is further extracted to a corner portion at the −X axis side and the +Z' axis side on the surface at the −Y' axis side of the framing portion **132**. The second extraction electrode **435***b* is formed from the second excitation electrode **134***b* to a corner portion at the +X axis side and the −Z' axis side on the surface at the −Y' axis side of the framing portion **132** via the connecting portion **133**.

[0086] FIG. **11**B is a cross-sectional view taken along the line E-E of FIG. **11**A. In the piezoelectric vibrating piece **430**, the first extraction electrode **435***a* on the connecting portion **133** has a width L**2** in the Z' axis direction on the surface of at the +Y' axis side, and has the width L**2** in the Z' axis direction on the surface at the −Y' axis side. The second extraction

electrode **435***b* on the connecting portion **133** has a width L**3** in the Z' axis direction, which is larger than the width L**2**. Further, in the piezoelectric vibrating piece **430**, the first extraction electrode **435***a* is an only electrode formed on the surface at the +Y' axis side of the connecting portion **133**, while the first extraction electrode **435***a* and the second extraction electrode **435***b* are formed on the surface at the −Y' axis side. That is, an area of electrode formed on the surface at the +Y' axis side of the connecting portion **133** is smaller than areas of the electrodes formed on the surface at the −Y' axis side of the connecting portion **133**.

[0087] In the case where the connecting portion of the piezoelectric vibrating piece is formed to have a narrow width in the Z' axis direction, areas of the extraction electrodes formed on the connecting portion are also small. At this time, the reverse sputtering performed on the piezoelectric vibrating piece increases electrical resistances of the extraction electrodes formed on the surface at the +Y' axis side of the connecting portion. In the piezoelectric vibrating piece **430**, the electrodes formed on the surface at the +Y' axis side of the connecting portion **133** are formed to have small area, thus being insusceptible to the reverse sputtering. The first extraction electrode **435***a* is also formed on the side face of the connecting portion **133**, thus ensuring an area at the connecting portion **133**.

Configuration of a Piezoelectric Vibrating Piece **530**

[0088] FIG. **12**A is a plan view of the piezoelectric vibrating piece **530**. The piezoelectric vibrating piece **530** includes the excitation unit **131**, the framing portion **132**, and the connecting portion **133**. In the excitation unit **131**, the first excitation electrode **134***a* and the second excitation electrode **134***b* are respectively formed on the surface at the +Y' axis side and the surface at the −Y' axis side of the excitation unit **131**. A first extraction electrode **535***a* and a second extraction electrode **535***b* are respectively extracted from the first excitation electrode **134***a* and the second excitation electrode **134***b*. The first extraction electrode **535***a* extends from the first excitation electrode **134***a* in the −X axis direction on the surface at the +Y' axis side of the piezoelectric vibrating piece **530**. Then, the first extraction electrode **535***a* is extracted to a side at the +Z' axis side of the connecting portion **133**, a side that faces the through-hole **136** in the +X axis direction in the framing portion **132**, and a side that faces the through-hole **136** in the −Z' axis direction in the framing portion **132**. Further, the first extraction electrode **535***a* is extracted to the surface at the −Y' axis side via a side-surface electrode **539***a* formed on the side face of the through-hole **136**, and then extends to a corner portion at the −X axis side and +Z' axis side on the surface at the −Y' axis side of the framing portion **132**. The side-surface electrode **539***a* is formed on the side face **133***a* at the +Z' axis side of the connecting portion **133**. The side-surface electrode **539***a* is also formed on the side face that faces the through-hole **136** in the +X axis direction in the framing portion **132**, at the +Z' axis side of the connecting portion **133**. The side-surface electrode **539***a* is also formed on the side face that faces the through-hole **136** in the −Z' axis direction in the framing portion **132** at the −X axis side. The second extraction electrode **535***b* extends from the second excitation electrode **134***b* in the −X axis direction, and then extracted to the framing portion **132** via the connecting portion **133**. Further, the second extraction electrode **535***b* extends along the framing portion **132** in the −Z' axis direction and then in the +X axis direction. The second extraction electrode **535***b* is then formed to a corner portion at the +X axis side and the −Z' axis side on the surface at the −Y' axis side of the framing portion **132**. The second extraction electrode **535***b* is also formed at the side-surface electrode **539***b* and on peripheral areas of the side-surface electrode **539***b* on the surface at the +Y' axis side of the piezoelectric vibrating piece **530**. The side-surface electrode **539***b* is formed on a side face **133***b* at the −Z' axis side of the connecting portion **133**. The side-surface electrode **539***b* is also formed on the side face that faces the through-hole **136** in the +X axis direction in the framing portion **132** in the −Z' axis side of the connecting portion **133**. The side-surface electrode **539***b* is also formed on the side face that faces the through-hole **136** in the +Z' axis direction in the framing portion **132** at the −X axis side. The side-surface electrode **539***b* is also formed on the surface at the +Y' axis side of the piezoelectric vibrating piece **530**. The side-surface electrode **539***b* on the surface at the +Y' axis side is formed along the side at the −Z' axis side of the connecting portion **133**. The side-surface electrode **539***b* on the surface at the +Y' axis side is also formed along a side that faces the through-hole **136** in the +X axis direction in the framing portion **132** at the −Z' axis side. The side-surface electrode **539***b* on the surface at the +Y' axis side is also formed along a side that faces the through-hole **136** in the +Z' axis direction in the framing portion **132** at the −X axis side.

[0089] FIG. **12**B is a cross-sectional view taken along the line F-F of FIG. **12**A. The first extraction electrode **535***a* and the second extraction electrode **535***b* are each formed on the surface at the +Y' axis side and the surface at the −Y' axis side of the connecting portion **133**, and respectively formed on the side face **133***a* and the side face **133***b* of the connecting portion **133**. The first extraction electrode **535***a* and the second extraction electrode **535***b* are each formed on the surface at the +Y' axis side of the framing portion **132**, the surface at the −Y' axis side of the framing portion **132**, and the side faces at the through-hole **136** side of the framing portion **132**. Further, the first extraction electrode **535***a* and the second extraction electrode **535***b* do not overlap with one another in the Y' axis direction at the connecting portion **133**.

[0090] In the piezoelectric vibrating piece **530**, the first extraction electrode **535***a* and the second extraction electrode **535***b* are formed on the surface at the +Y' axis side, the surface at the −Y' axis side, and the side faces of the connecting portion **133**. This forms large areas of the first extraction electrode **535***a* and the second extraction electrode **535***b* at the connecting portion **133**. Thus, even if the connecting portion **133** has a small width in the Z' axis direction, this minimizes increase in electrical resistance caused by the decreased areas of extraction electrodes.

Configuration of a Piezoelectric Vibrating Piece **630**

[0091] FIG. **13**A is a plan view of the piezoelectric vibrating piece **630**. The piezoelectric vibrating piece **630** includes an excitation unit **631**, the framing portion **132**, and the connecting portion **133**. The excitation unit **631** is formed in a rectangular shape that includes the first side **138***a* and the second sides **138***b*. The excitation unit **631** is separated into a first region **131***a*, a third region **131***c*, and a fourth region **131***d*. The first region **131***a* is a region that is directly connected to the connecting portion **133**. The third region **131***c* is a region where the first excitation electrode **134***a* and the second excitation electrode **134***b* are formed. The fourth region **131***d* is a region other than the first region **131***a* and the third region **131***c*, and is formed between the first region **131***a*

and the third region **131***c*. The piezoelectric vibrating piece **630** is a mesa-type piezoelectric vibrating piece. In the piezoelectric vibrating piece **630**, the third region **131***c*, on which the first excitation electrode **134***a* and the second excitation electrode **134***b* are formed, is thicker than the fourth region **131***d*, which surrounds the third region **131***c*, in the Y' axis direction. And, a first extraction electrode **635***a* and a second extraction electrode **635***b* are respectively extracted from the first excitation electrode **134***a* and the second excitation electrode **134***b*, which are formed on the third region **131***c* of the excitation unit **631**, to the framing portion **132**.

[0092] FIG. **13**B is a cross-sectional view taken along the line G-G of FIG. **13**A. The piezoelectric vibrating piece **630** has, for example, a thickness of T**2** in the Y' axis direction at the third region **131***c* of the excitation unit **631** and a thickness of T**3** in the Y' axis direction at the fourth region **131***d*. Thicknesses in the Y' axis direction of the connecting portion **133**, the framing portion **132**, and the first region **131***a* are respectively formed to be the thickness T**2**, the thickness T**1**, and the thickness T**2**, similarly to the piezoelectric vibrating piece **130** illustrated in FIG. **4**B.

[0093] FIG. **13**C is a partial plan view of the piezoelectric vibrating piece **630** illustrating electrodes on the surface at the +Y' axis side. FIG. **13**C illustrates a half plan view of the piezoelectric vibrating piece **630** at the −X axis side. The first extraction electrode **635***a* is extracted from the first excitation electrode **134***a* on the surface at the +Y' axis side. Then, the first extraction electrode **635***a* on the surface at the +Y' axis side is formed along the side face **133***a* of the connecting portion **133**. The first extraction electrode **635***a* on the surface at the +Y' axis side is also formed along the first side **138***a* in the +Z' axis side of the connecting portion **133** and the second side **138***b* at the −X axis side in the +Z' axis side of the connecting portion **133**. The first extraction electrode **635***a* on the surface at the +Y' axis side is also formed along a side that faces the through-hole **136** at the +X axis side of the framing portion **132** in the +Z' axis side of the connecting portion **133**. The first extraction electrode **635***a* on the surface at the +Y' axis side is also formed along a side that faces the through-hole **136** in the −Z' axis direction in the framing portion **132** at the −X axis side. The second extraction electrode **635***b* is formed along the side face **133***b* of the connecting portion **133**, the first side **138***a* in the −Z' axis side of the connecting portion **133** and the second side **138***b* at the −X axis side in the −Z' axis side of the connecting portion **133**. The second extraction electrode **635***b* is also formed along a side that faces the through-hole **136** at the +X axis side of the framing portion **132** in the −Z' axis side of the connecting portion **133**. The second extraction electrode **635***b* is also formed along a side that faces the through-hole **136** at the +Z' axis side of the framing portion **132** at the −X axis side. The second extraction electrode **635***b* is then connected to a side-surface electrode **639***b*. The first extraction electrode **635***a* includes a portion that is formed on the surface at the +Y' axis side of the piezoelectric vibrating piece **630** and extracted to the surface at the −Y' axis side via a side-surface electrode **639***a*, which is formed at the side face of the through-hole **136**. The side-surface electrode **639***a* is formed on the side face **133***a* at the +Z' axis side of the connecting portion **133**, the first side **138***a* in the +Z' axis side of the connecting portion **133**, and the second side **138***b* at the −X axis side in the +Z' axis side of the connecting portion **133**. The side-surface electrode **639***a* is also formed on a side face that faces the through-hole **136** in the +X axis direction of the framing portion **132** in the +Z' axis side of the connecting portion **133**. The side-surface electrode **639***a* is also formed on a side face that faces the through-hole **136** in the −Z' axis direction of the framing portion **132** at the −X axis side. The side-surface electrode **639***b* is formed on the side face **133***b* at the −Z' axis side of the connecting portion **133**. The side-surface electrode **639***b* is also formed on the first side **138***a* in the −Z' axis side of the connecting portion **133** and the second side **138***b* at the −X axis side in the −Z' axis side of the connecting portion **133**. The side-surface electrode **639***b* is also formed on a side face that faces the through-hole **136** in the +X axis direction of framing portion **132** in the −Z' axis side of the connecting portion **133**. The side-surface electrode **639***b* is also formed on a side face that faces the through-hole **136** in the +Z' axis direction of the framing portion **132** at the −X axis side.

[0094] FIG. **13**D is a partial plan view of the piezoelectric vibrating piece **630** illustrating electrodes on the surface at the −Y' axis side. FIG. **13**D illustrates a half plan view of the piezoelectric vibrating piece **630** at the −X axis side. The first extraction electrode **635***a* is extracted on the surface at the −Y' axis side from the side-surface electrode **639***a* to a peripheral area of the side-surface electrode **639***a* on the surface at the −Y' axis side of the piezoelectric vibrating piece **630**. Further, the first extraction electrode **635***a* is extracted to a corner portion at the −X axis side and the +Z' axis side of the framing portion **132**. The second extraction electrode **635***b* extends in the −X axis direction from the second excitation electrode **134***b* and is extracted to the framing portion **132**. The second extraction electrode **635***b* then extends in the −Z' axis direction and the +X axis direction, and is extracted to a corner portion at the +X axis side and the −Z' axis side of the framing portion **132**. The second extraction electrode **635***b* is also extracted to a peripheral area of the side-surface electrode **639***b* on the surface at the −Y' axis side, and electrically connected to the second extraction electrode **635***b*, which is formed at the +Y' axis side, via the side-surface electrode **639***b*.

[0095] The piezoelectric vibrating piece **630** is formed to have large areas of the side-surface electrodes. Thus, even if the connecting portion **133** is formed to have a small width in the Z' axis direction, this minimizes increase in electrical resistance due to decreased area of the extraction electrodes formed on the connecting portion **133**. This also avoids increase in electrical resistances of the side-surface electrodes, which tend to be thin and have high electrical resistance.

Configuration of a Piezoelectric Vibrating Piece **730**

[0096] FIG. **14**A is a plan view of the piezoelectric vibrating piece **730**. The piezoelectric vibrating piece **730** includes the excitation unit **131**, the framing portion **132**, and the connecting portion **133**. In the excitation unit **131**, the first excitation electrode **134***a* and the second excitation electrode **134***b* are respectively formed on the surface at the +Y' axis side and the surface at the −Y' axis side of the excitation unit **131**. A first extraction electrode **735***a* and a second extraction electrode **735***b* are respectively extracted from the first excitation electrode **134***a* and the second excitation electrode **134***b*. The first extraction electrode **735***a* is extracted from the first excitation electrode **134***a* to a corner portion at the −X axis side and the +Z' axis side that faces the through-hole **136** of the framing portion **132**. Further, the first extraction electrode **735***a* is extracted to the surface at the −Y' axis side via a side-surface electrode **739***c* that is formed on a side face of

the framing portion **132**. This side face includes a corner portion at the −X axis side and the +Z' axis side that faces the through-hole **136**. The first extraction electrode **735***a* extends to a corner portion at the +Z' axis side and the −X axis side of the framing portion **132**. The second extraction electrode **735***b* extends from the second excitation electrode **134***b* to the framing portion **132** via the connecting portion **133**. Further, the second extraction electrode **735***b* extends in the −Z' axis direction and the +X axis direction along the surface at the −Y' axis side of the framing portion **132**. The second extraction electrode **735***b* extends to a corner portion at the +X axis side and the −Z' axis side of the framing portion **132**. The first extraction electrode **735***a* and the second extraction electrode **735***b* respectively includes a side-surface electrode **739***a*, which is formed on the side face **133***a* of the connecting portion **133**, and a side-surface electrode **739***b*, which is formed on the side face **133***b* of the connecting portion **133**.

[0097] FIG. **14**B is a cross-sectional view taken along the line H-H of FIG. **14**A. The first extraction electrode **735***a* and the second extraction electrode **735***b* respectively include the side-surface electrode **739***a* and the side-surface electrode **739***b* on the connecting portion **133**. The side-surface electrode **739***a* is formed on the half of the side face **133***a* at the +Y' axis side of the connecting portion **133**, while the side-surface electrode **739***b* is formed on the half of the side face **133***b* at the −Y' axis side of the connecting portion **133**. The first extraction electrode **735***a* and the second extraction electrode **735***b* do not overlap with one another in the Y' axis direction or the Z' axis direction at the connecting portion **133**.

[0098] In the piezoelectric vibrating piece **730**, the first extraction electrode **735***a* and the second extraction electrode **735***b*, which are formed on the connecting portion **133**, do not overlap with one another in the Y' axis direction or the Z' axis direction at the connecting portion. Thus, in the piezoelectric vibrating piece **730**, the first extraction electrode **735***a* and the second extraction electrode **735***b* do not generate capacitance at the connecting portion **133**. The first extraction electrode **735***a* and the second extraction electrode **735***b* each preferably have a large area at the connecting portion **133** because the electrodes are also formed on the side faces of the connecting portion **133**.

[0099] Representative embodiments have been described in detail above. As evident to those skilled in the art, the present invention may be changed or modified in various ways within the technical scope of the invention.

[0100] For example, while only the piezoelectric vibrating piece **630** is described as a mesa-type piezoelectric vibrating piece, the other piezoelectric vibrating pieces may be formed as mesa-type piezoelectric vibrating pieces.

[0101] While in the embodiments the piezoelectric vibrating pieces are AT-cut quartz-crystal vibrating pieces, for example, a BT-cut quartz-crystal vibrating piece that vibrates in a thickness-shear vibration mode may also be used, similarly to the AT-cut quartz-crystal vibrating pieces. Further, the piezoelectric vibrating pieces are basically applied to piezoelectric material including not only quartz-crystal material but also lithium tantalite, lithium niobate, and piezoelectric ceramic.

What is claimed is:

1. A piezoelectric vibrating piece to be bonded to and sandwiched between a lid plate and a base plate with an external electrode, the piezoelectric vibrating piece having a first main surface at the lid plate side and a second main surface at the base plate side, the piezoelectric vibrating piece comprising:

an excitation unit in a rectangular shape, including a first side and a second side, the first side extending in a first direction, the second side extending in a second direction perpendicular to the first direction;

a first excitation electrode, on the first main surface of the excitation unit;

a second excitation electrode, on the second main surface of the excitation unit;

a framing portion, including a first bonding surface and a second bonding surface, the first bonding surface being a surface to be bonded to the lid plate, the second bonding surface being a surface to be bonded to the base plate, the framing portion surrounding the excitation unit;

one connecting portion, connecting the first side of the excitation unit and the framing portion together, the connecting portion including a planar surface parallel to both the main surfaces and a side face intersecting with the planar surface;

a first extraction electrode, being extracted from the first excitation electrode to the second bonding surface of the framing portion via the connecting portion; and

a second extraction electrode, being extracted from the second excitation electrode to the second bonding surface of the framing portion via the connecting portion,

wherein, the first extraction electrode is disposed on at least a part of the side face of the connecting portion, and the first extraction electrode is extracted to the framing portion.

2. The piezoelectric vibrating piece according to claim **1**, wherein,

the first extraction electrode and the second extraction electrode do not overlap with one another in a confronting direction of the planar surfaces or in a confronting direction of the side faces of the connecting portion.

3. The piezoelectric vibrating piece according to claim **2**, wherein,

the first extraction electrode is disposed on the side face of the connecting portion, the first main surface, and the second main surface, and

the second extraction electrode is disposed only on the second main surface of the connecting portion.

4. The piezoelectric vibrating piece according to claim **3**, wherein,

a width of the first extraction electrode on the second main surface of the connecting portion in the confronting direction of the side faces is smaller than a width of the second extraction electrode on the second main surface of the connecting portion in the confronting direction of the side faces.

5. The piezoelectric vibrating piece according to claim **1**, wherein,

the first extraction electrode has a first length extracted from one end of the first excitation electrode side to another end, the other end extending to the second bonding surface,

the second extraction electrode has a second length extracted from one end of the second excitation electrode side to another end, the other end extending to the second bonding surface,

the first length is shorter than the second length,

the first excitation electrode is thinner than the second excitation electrode, and

a part of the first extraction electrode is thinner than the second extraction electrode.

6. The piezoelectric vibrating piece according to claim **1**, wherein,

the first extraction electrode is disposed on the first bonding surface of the framing portion, and

a total area of the first extraction electrode and the second extraction electrode at the lid plate side of the connecting portion is smaller than a total area of the first extraction electrode and the second extraction electrode at the base plate side of the connecting portion.

7. The piezoelectric vibrating piece according to claim **1**, wherein,

the first extraction electrode is disposed on a side face of the first side of the excitation unit.

8. The piezoelectric vibrating piece according to claim **7**, wherein,

the first extraction electrode is disposed on a side face of the framing portion, the side face intersecting with both the bonding surfaces.

9. The piezoelectric vibrating piece according to claim **5**, wherein,

a width of a portion of the first extraction electrode where the first extraction electrode connects the first excitation electrode is larger than a width of a portion of the second extraction electrode where the second excitation electrode connects the second extraction electrode.

10. The piezoelectric vibrating piece according to claim **1**, wherein,

the connecting portion has a first thickness in the confronting direction of the planar surfaces,

the excitation unit includes:

a first region, including at least a part of the first side, the first region with the first thickness being directly connected to the connecting portion in the confronting direction of the planar surfaces; and

a second region, other than the first region where the first and the second excitation electrodes are disposed, and

a thickness of the second region in the confronting direction of the planar surfaces is thinner than a thickness of the first region in the confronting direction of the planar surfaces.

11. The piezoelectric vibrating piece according to claim **1**, wherein,

the connecting portion has a first thickness in the confronting direction of the planar surfaces, and

the excitation unit includes:

a first region, including at least a part of the first side, the first region with the first thickness being directly connected to the connecting portion in the confronting direction of the planar surfaces;

a third region, having a second thickness in the confronting direction of the planar surfaces, the first and the second excitation electrodes being disposed on the third region; and

a fourth region, other than the first region and the third region, the fourth region having a third thickness in the confronting direction of the planar surfaces, the fourth region being disposed between the first region and the third region,

wherein, the first thickness and the second thickness are thicker than the third thickness.

12. A piezoelectric device comprising:

the piezoelectric vibrating piece according to claim **1**;

the lid plate; and

the base plate,

wherein, the piezoelectric vibrating piece is sandwiched between the lid plate and the base plate.

13. A method for manufacturing a piezoelectric device comprising:

forming outlines of a plurality of piezoelectric vibrating pieces on a piezoelectric wafer, the piezoelectric having a first main surface and a second main surface, the piezoelectric wafer including a piezoelectric material, the piezoelectric vibrating piece including:

an excitation unit, configured to vibrate at a predetermined vibration frequency;

a framing portion, surrounding the excitation unit; and

one connecting portion, connecting the excitation unit and the framing portion together;

forming electrodes, the electrodes including:

a first excitation electrode and a second excitation electrode, respectively disposed on the first main surface and the second main surface of the excitation unit;

a first extraction electrode, having a first length extracted from one end of the first excitation electrode side to another end of the second bonding surface of the framing portion via the connecting portion, the first extraction electrode being disposed on at least a part of a side face of the connecting portion; and

a second extraction electrode, having a second length extracted from one end of the second excitation electrode side to another end of the second bonding surface of the framing portion via the connecting portion, the second length being longer than the first length;

preparing a lid wafer including a plurality of lid plates;

preparing a base wafer including a plurality of base plates;

bonding the second main surface of the piezoelectric wafer to the base wafer via the sealing material;

adjusting vibration frequency of the excitation unit by reverse sputtering on the first excitation electrode, the first excitation electrode being disposed on the first main surface of the piezoelectric wafer; and

bonding the first main surface of the piezoelectric wafer to the lid wafer via the sealing material.

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