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YAMADA et al.

(54) **PIEZOELECTRIC VIBRATION ELEMENT AND PIEZOELECTRIC DEVICE**

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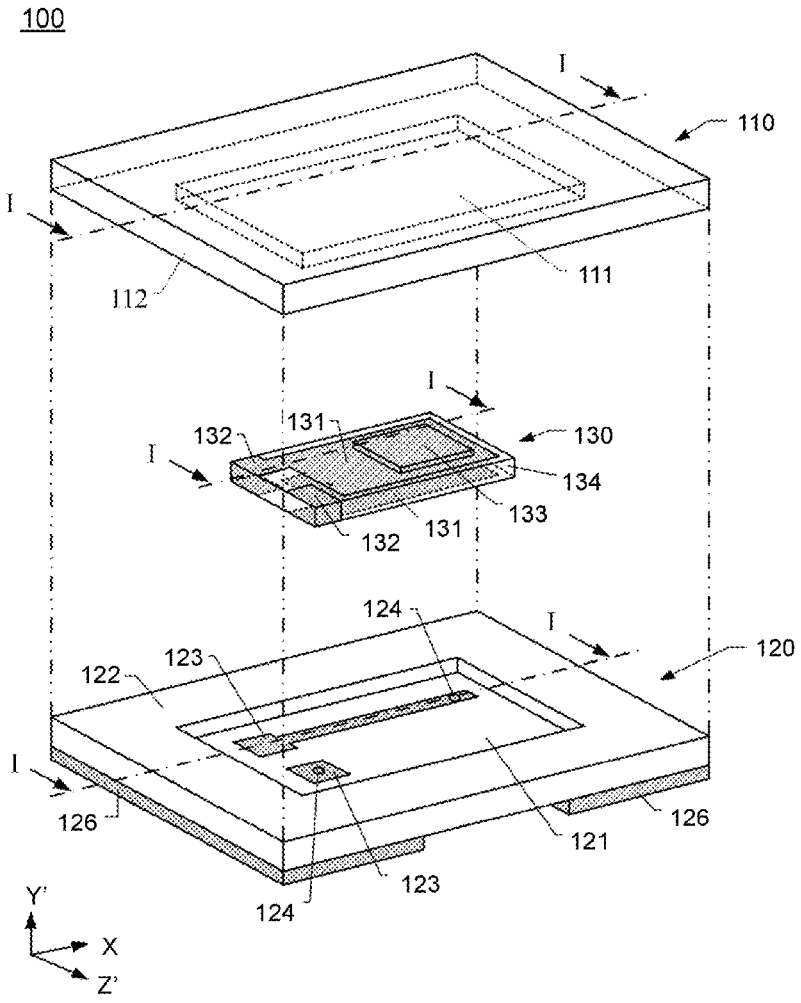
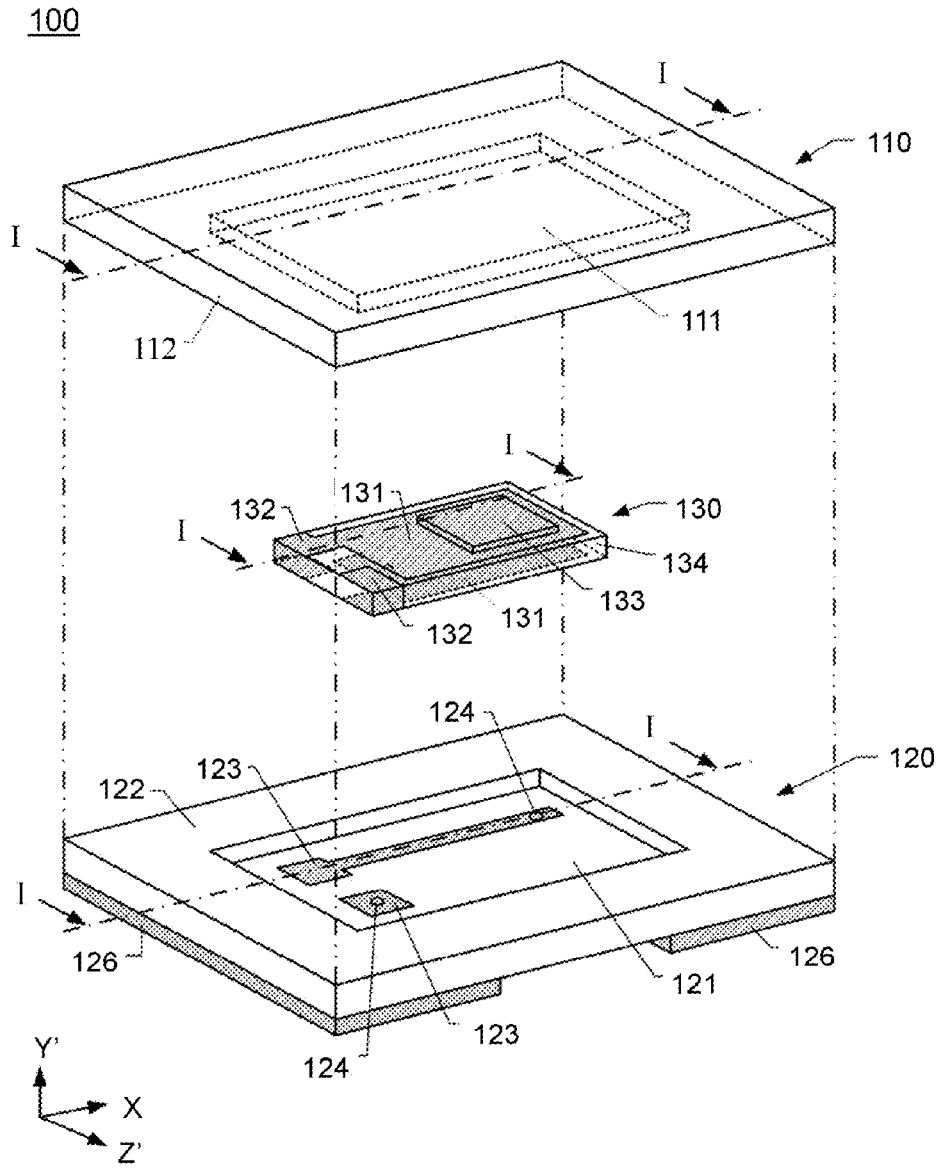
USPC **310/366**

(57) **ABSTRACT**

A piezoelectric vibration element includes a piezoelectric piece, a pair of excitation electrodes, and a pair of extraction electrodes. The piezoelectric piece has a rectangular shape with long sides and short sides and a first principal surface and a second principal surface. The piezoelectric piece includes a mesa portion thicker than a peripheral portion at least on the first principal surface. The excitation electrode is larger than an area of the mesa portion and covers the mesa portion on the principal surface where the mesa portion is formed. The excitation electrode has a center away from a center of the piezoelectric piece toward another short side by a first distance. The mesa portion has a center away from the center of the piezoelectric piece to the other short side by a second distance. The second distance is different from the first distance.

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I
110
I
112
111
I
131
132
130
I
134
133
131
132
124
I
120
123
122
I
126
121
126
123
124
Y'
X
Z'

FIG.1

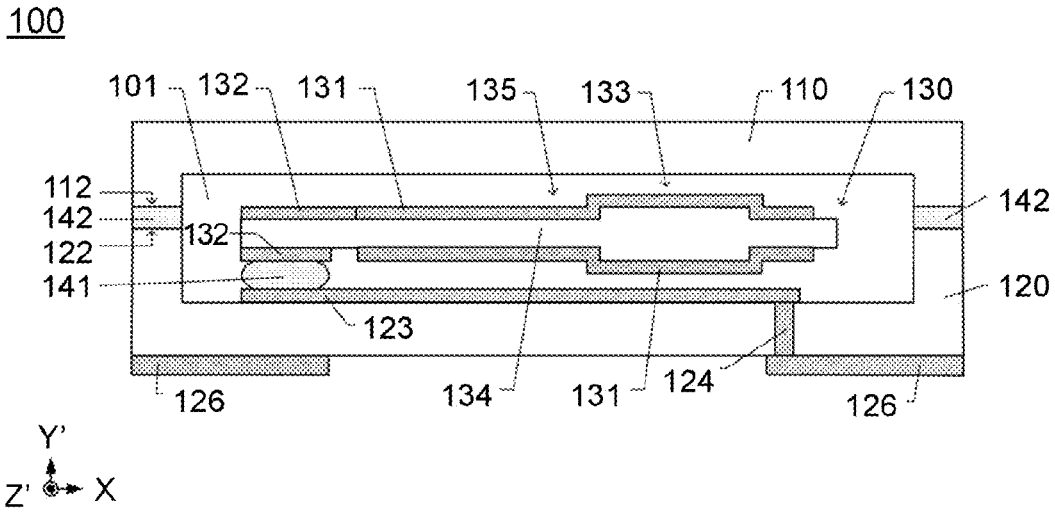

100
101
132
131
135
133
110
130
112
142
122
141
132
142
120
123
126
134
131
124
126
Y'
Z'
X

FIG.2

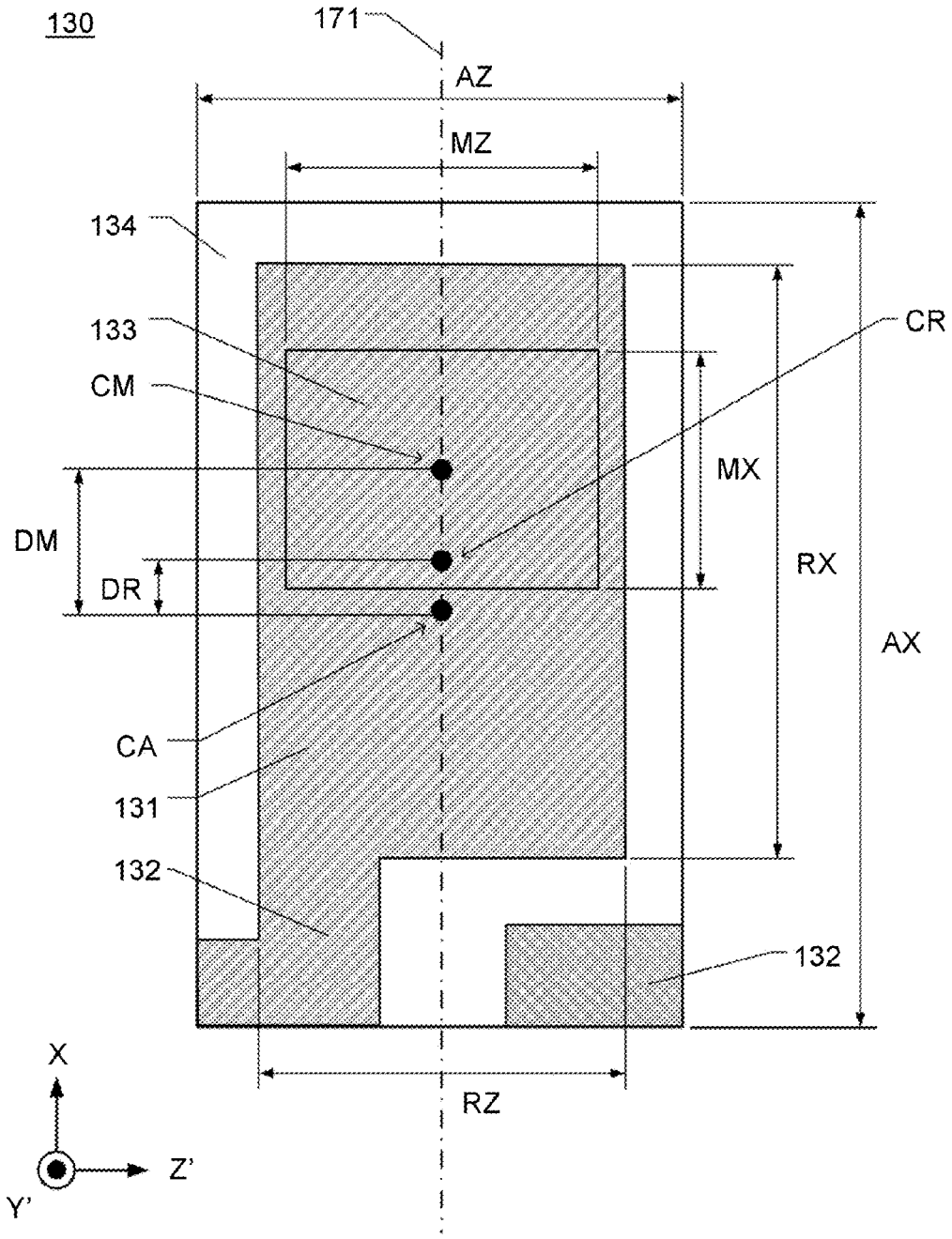


FIG.3

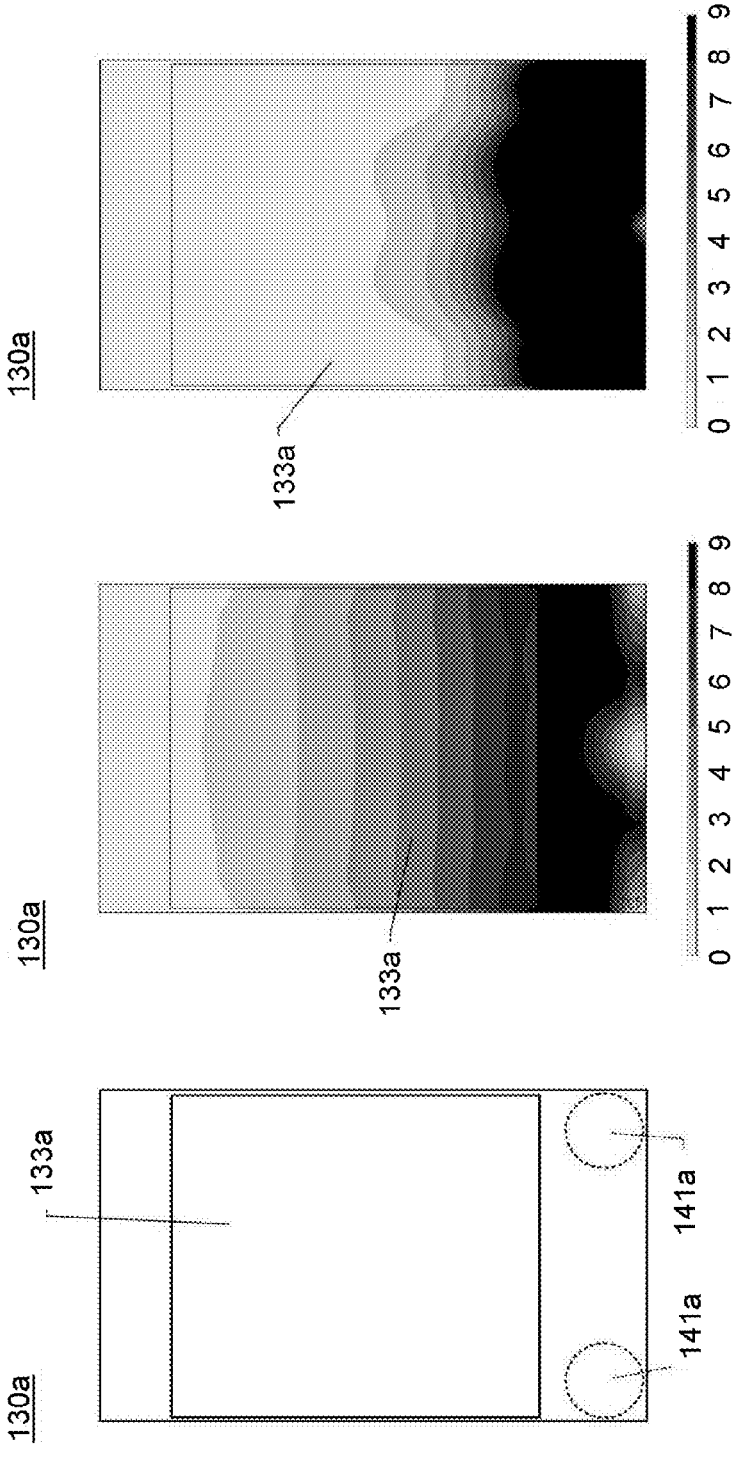


FIG.4A

FIG.4B

FIG.4C

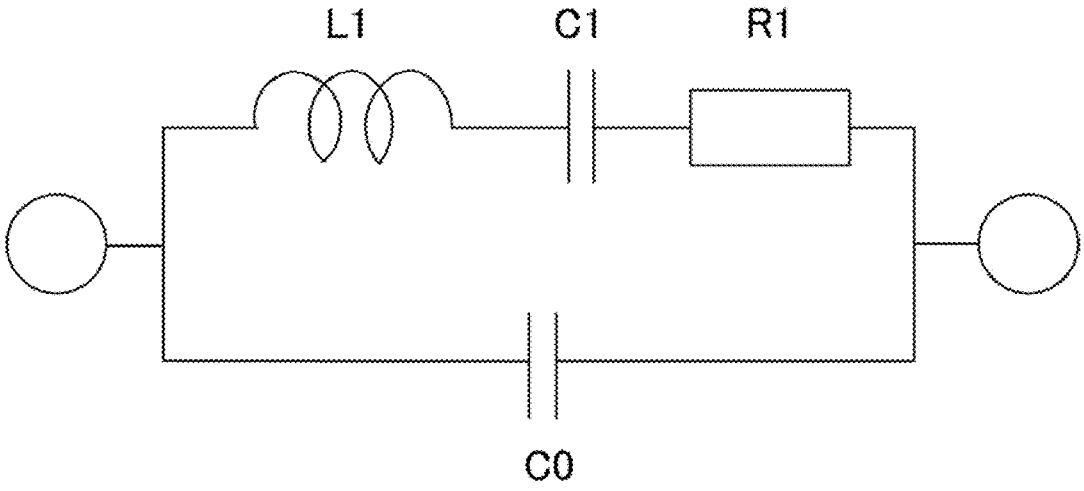


FIG.5

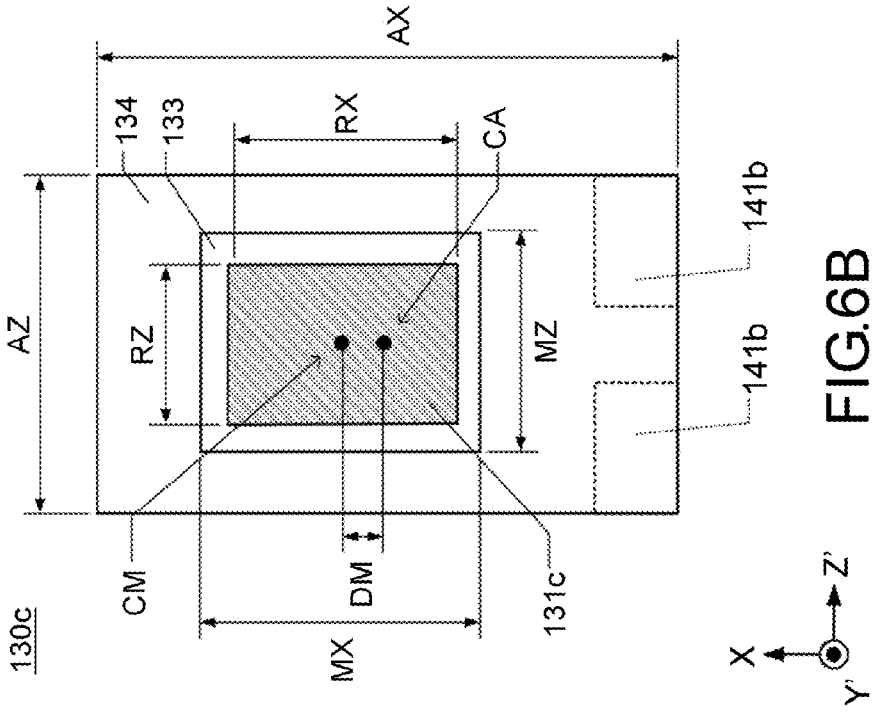

AX
134
133
RX
CA
AZ
RZ
MZ
141b
141b
CM
DM
131c
MX
130c
X
Z'
Y'

FIG.6B

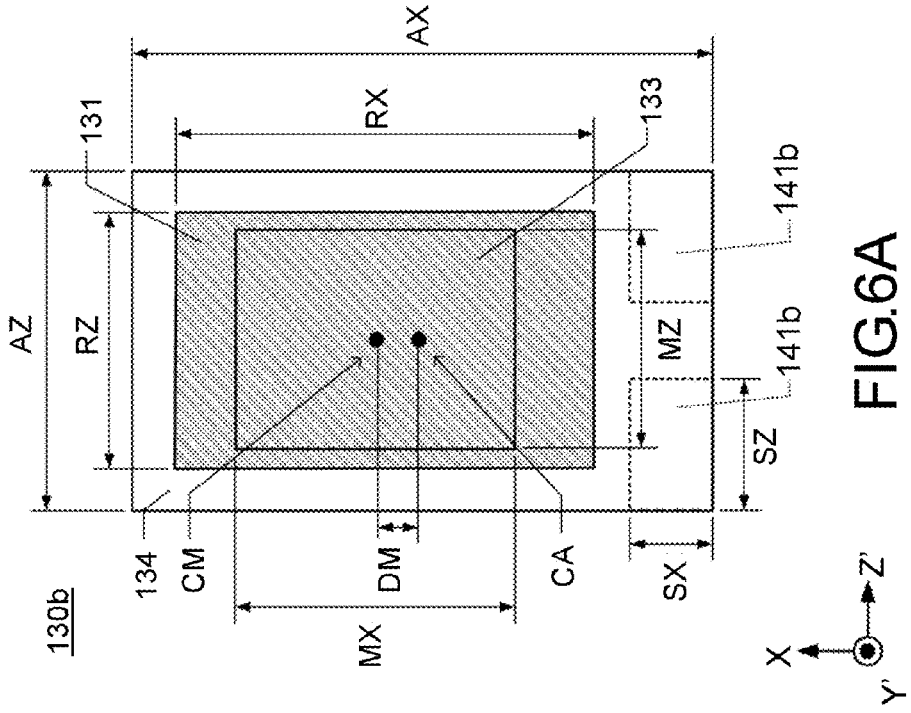

AX
131
RX
133
141b
AZ
RZ
MZ
141b
SZ
134
CM
DM
CA
SX
MX
130b
X
Z'
Y'

FIG.6A

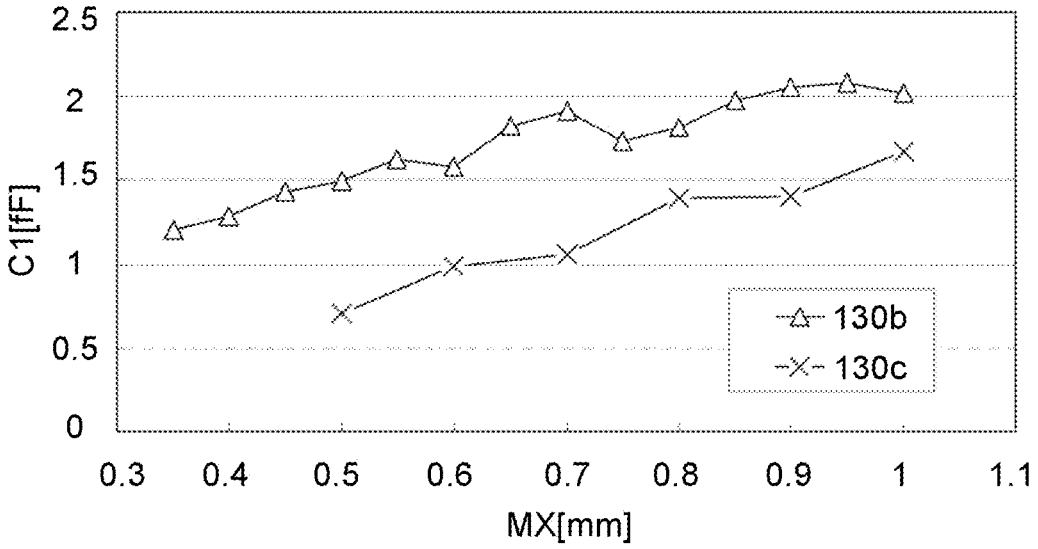

2.5
2
1.5
1
0.5
0
C1[fF]
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
MX[mm]
130b
130c

FIG.7A

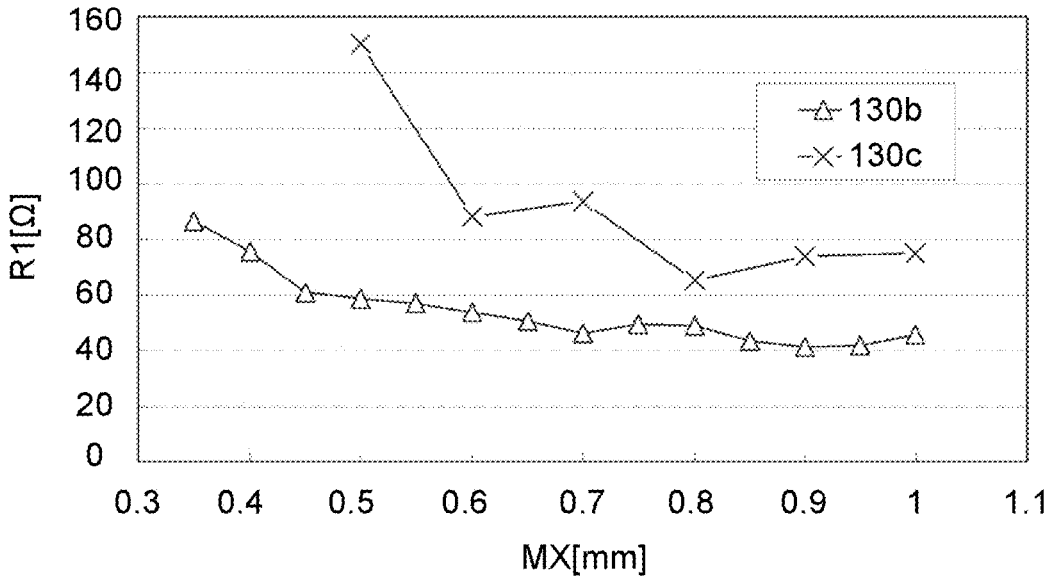

160
140
120
100
80
60
40
20
0
R1[Ω]
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
MX[mm]
130b
130c

FIG.7B

	Dimensions of excitation electrode			Dimensions of mesa portion	
Piezoelectric vibration element	RX	RZ	DR	MX	MZ
130d	0.89	0.64	0.0	0.4	0.6
130e	0.89	0.64	0.045	0.4	0.6
130f	1.1	0.64	0.1	0.6	0.6
130g	1.1	0.64	0.1	0.8	0.6

FIG.8

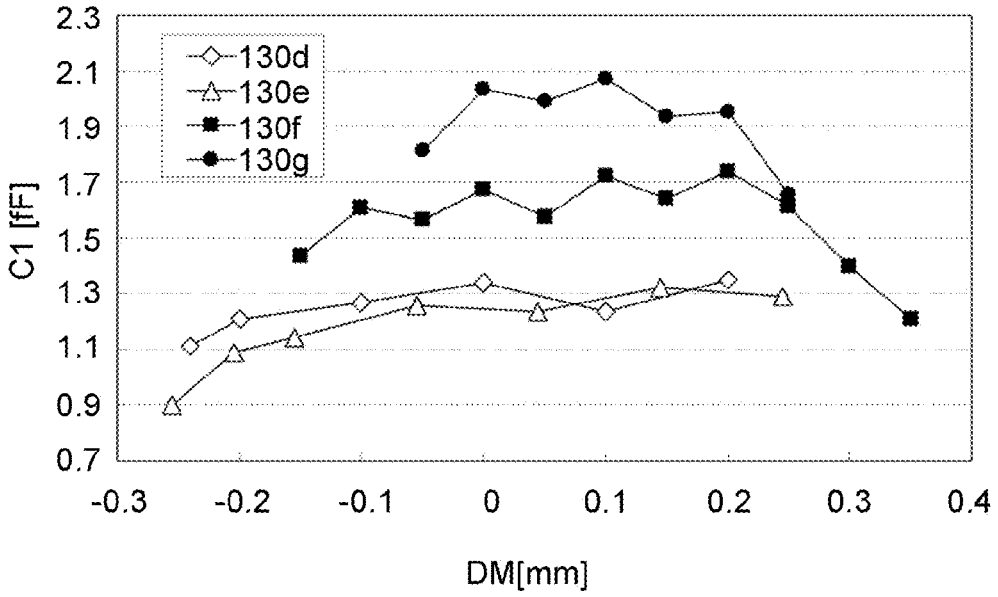

2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
C1 [fF]
130d
130e
130f
130g
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
DM[mm]

FIG.9A

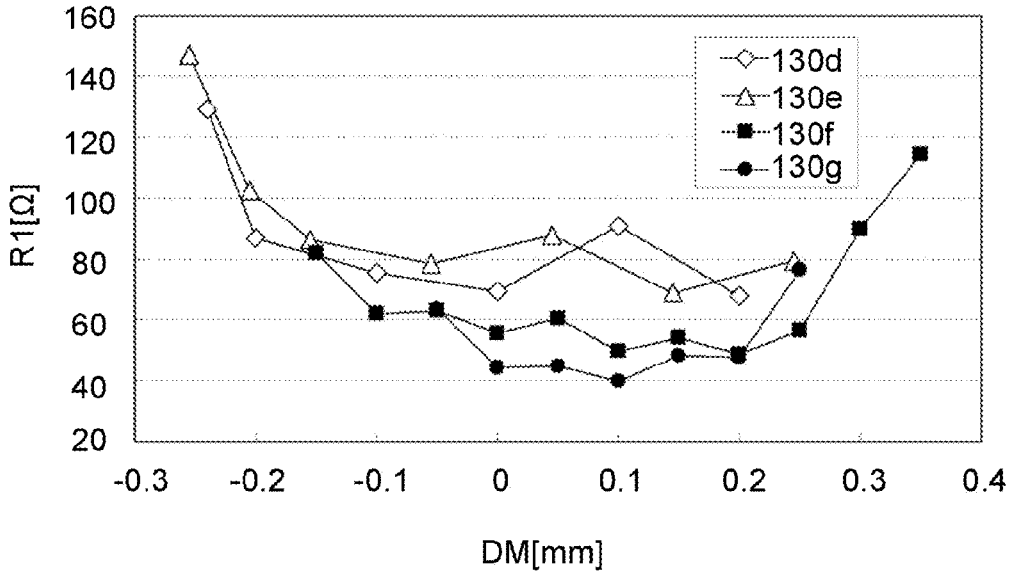

160
140
120
100
80
60
40
20
R1[Ω]
130d
130e
130f
130g
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
DM[mm]

FIG.9B

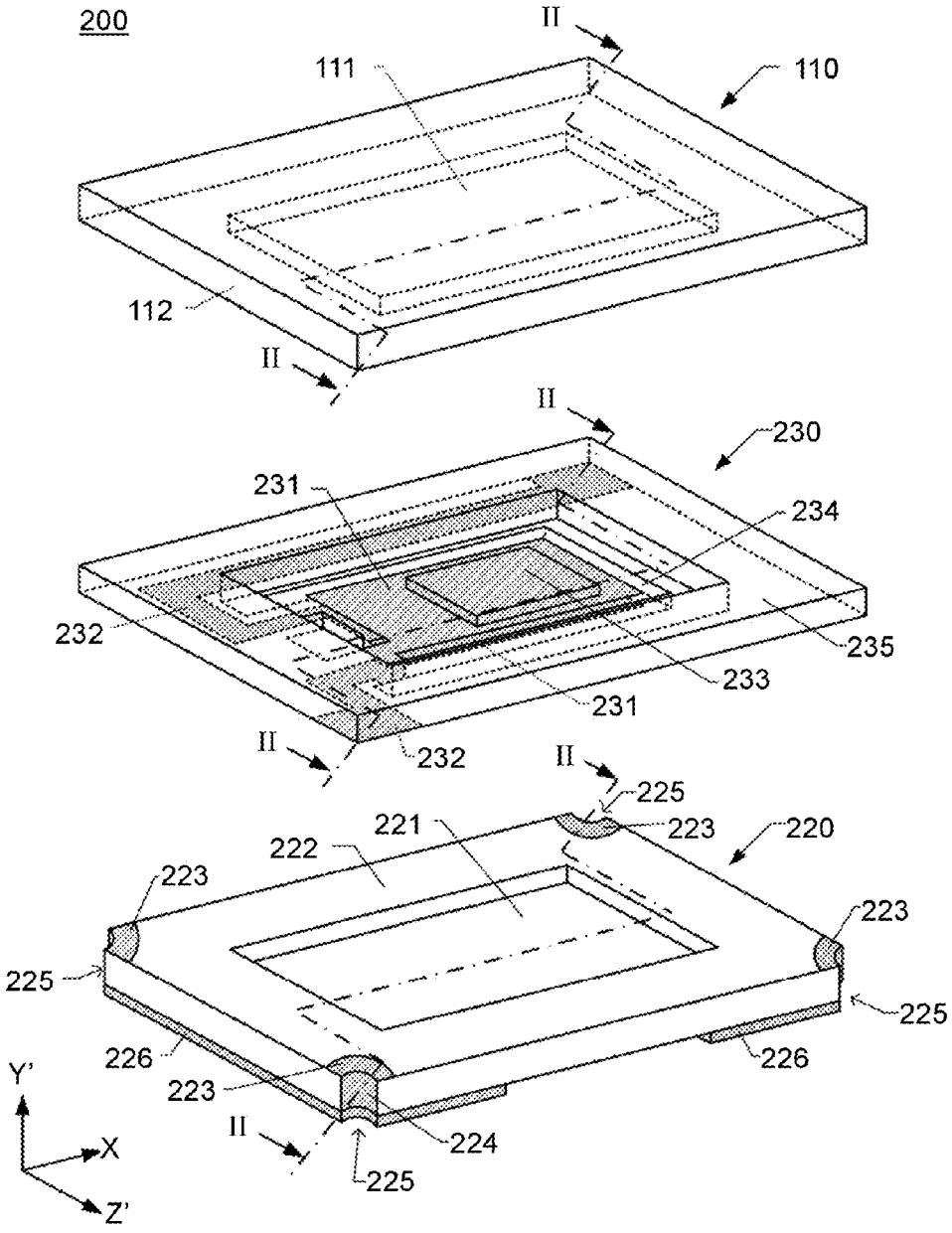
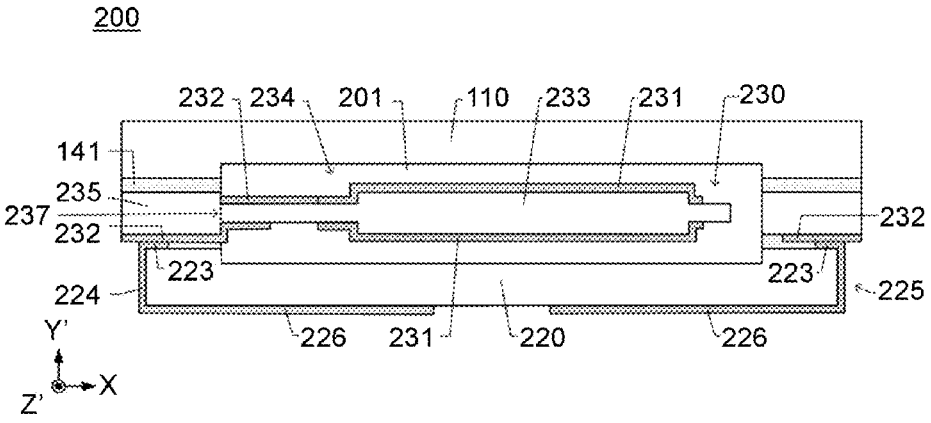

200
II
111
110
112
II
II
230
231
234
232
235
233
231
II
232
II
225
221
223
220
222
223
223
225
225
226
226
223
Y'
II
224
X
225
Z'

FIG.10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110
233
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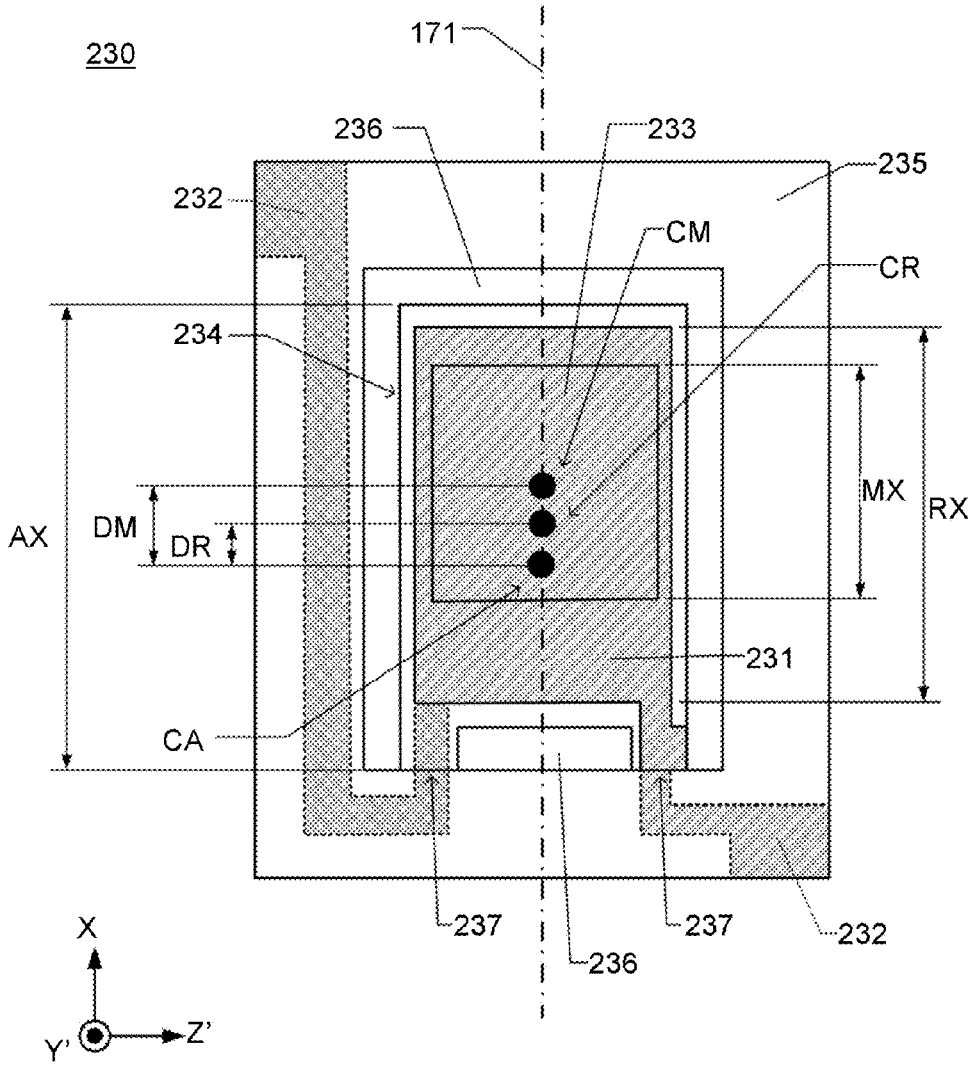
220
226
Y'
X
Z'

FIG.11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171
236
233
235
232
CM
CR
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AX
DM
DR
MX
RX
231
CA
237
237
232
236
X
Y'
Z'

FIG.12

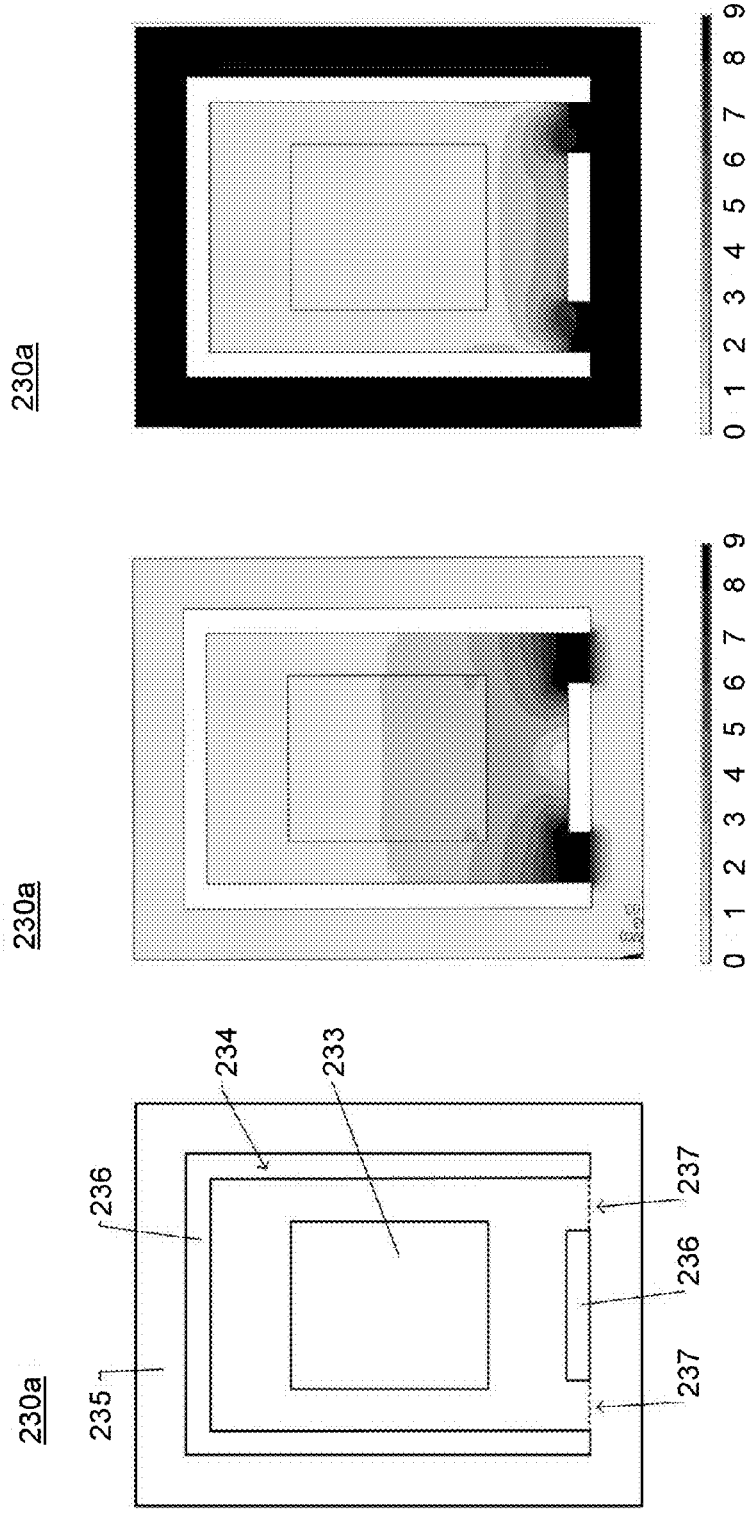

FIG.13A

FIG.13B

FIG.13C

PIEZOELECTRIC VIBRATION ELEMENT AND PIEZOELECTRIC DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit of Japan application serial no. 2012-033516, filed on Feb. 20, 2012. The entirety of the above-mentioned patent application is hereby incorporated by reference herein and made a part of this specification.

TECHNICAL FIELD

[0002] This disclosure relates to a piezoelectric vibration element and a piezoelectric device that include a mesa-type piezoelectric piece with improved vibration characteristic where a frequency variation is less generated by impact such as a drop and a temperature change.

DESCRIPTION OF THE RELATED ART

[0003] A piezoelectric piece that includes an excitation electrode and vibrates at a predetermined vibration frequency by applying a voltage to the excitation electrode and a piezoelectric vibration element including this piezoelectric piece are known. Placing this piezoelectric vibration element on a package forms a piezoelectric device. The piezoelectric piece includes a mesa portion, which is thicker than a peripheral portion of the piezoelectric piece, on the principal surface. This structure is known to improve a crystal impedance (CI) value. Further, in the piezoelectric vibration element and the piezoelectric device that include a mesa-type piezoelectric piece where this mesa portion is formed, it is known that a vibration characteristic changes by formation positions, sizes, and other conditions of the mesa portion and an electrode.

[0004] For example, Japanese Unexamined Patent Application Publication No. 2005-94410 discloses a mesa-type vibrating piece where an excitation electrode is formed larger than a mesa portion. This increases a frequency variable sensitivity and suppresses an unnecessary vibration. Additionally, this prevents an electrical short-circuit between a conductive adhesive and the excitation electrode by forming the mesa portion away from the conductive adhesive.

[0005] However, in the piezoelectric vibration element and the piezoelectric device, a frequency variation may be generated by stress applied to the piezoelectric piece by impact, such as a drop and a temperature change or similar causes. A countermeasure against this problem is required. A vibration characteristic is also required to be further improved.

[0006] A need thus exists for a piezoelectric vibration element and a piezoelectric device which are not susceptible to the drawback mentioned above.

SUMMARY

[0007] A piezoelectric vibration element according to a first aspect includes a piezoelectric piece, a pair of excitation electrodes on the first principal surface and the second principal surface, and a pair of extraction electrodes extracted from the pair of excitation electrodes to one of the short sides. The piezoelectric piece has a rectangular shape with long sides and short sides. The piezoelectric piece includes a first principal surface and a second principal surface. The second principal surface is a backside surface of the first principal surface. The piezoelectric piece includes a mesa portion at least on the first principal surface. The mesa portion is thicker than a peripheral portion. The excitation electrode is larger than an area of the mesa portion and covers the mesa portion on the principal surface where the mesa portion is formed. The excitation electrode has a center away from a center of the piezoelectric piece toward another short side by a first distance. The mesa portion has a center away from the center of the piezoelectric piece to the other short side by a second distance. The second distance is different from the first distance.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The foregoing and additional features and characteristics of this disclosure will become more apparent from the following detailed description considered with the reference to the accompanying drawings, wherein:

[0009] FIG. **1** is an exploded perspective view of a piezoelectric device **100**;

[0010] FIG. **2** is a cross-sectional view taken along the line I-I of FIG. **1**;

[0011] FIG. **3** is a plan view of a piezoelectric vibration element **130**;

[0012] FIG. **4**A is a plan view of a piezoelectric vibration element **130***a*;

[0013] FIG. **4**B is a plan view of the piezoelectric vibration element **130***a* where a simulation result of stress distribution at a drop of the piezoelectric device is illustrated;

[0014] FIG. **4**C is a plan view of the piezoelectric vibration element **130***a* where a simulation result of stress distribution at a temperature change of the piezoelectric device is illustrated;

[0015] FIG. **5** is a circuit diagram illustrating an equivalent circuit of the piezoelectric vibration element;

[0016] FIG. **6**A is a plan view of a piezoelectric vibration element **130***b*;

[0017] FIG. **6**B is a plan view of the piezoelectric vibration element **130***c*;

[0018] FIG. **7**A is a graph illustrating a relationship between a length MX of a mesa portion in the X-axis direction and an equivalent series capacitance C1;

[0019] FIG. **7**B is a graph illustrating a relationship between a length MX of a mesa portion in the X-axis direction and an equivalent series resistance R1;

[0020] FIG. **8** is a table listing dimensions of an excitation electrode and dimensions of the mesa portion of the piezoelectric vibration element;

[0021] FIG. **9**A is a graph illustrating a relationship between a second distance DM and the equivalent series capacitance C1;

[0022] FIG. **9**B is a graph illustrating a relationship between the second distance DM and the equivalent series resistance R1;

[0023] FIG. **10** is an exploded perspective view of a piezoelectric device **200**;

[0024] FIG. **11** is a cross-sectional view taken along the line II-II of FIG. **10**;

[0025] FIG. **12** is a plan view of a piezoelectric vibration element **230**;

[0026] FIG. **13**A is a plan view of a piezoelectric vibration element **230***a*;

[0027] FIG. **13**B is a plan view of the piezoelectric vibration element **230***a* where a simulation result of stress distribution at a drop of the piezoelectric device is illustrated; and

[0028] FIG. **13**C is a plan view of the piezoelectric vibration element **230***a* where a simulation result of stress distribution at a temperature change of the piezoelectric device is illustrated.

DETAILED DESCRIPTION

[0029] The preferred embodiments of this disclosure will be described with reference to the attached drawings. It will be understood that the scope of the disclosure is not limited to the described embodiments, unless otherwise stated.

Constitution of a Piezoelectric Device **100** of a First Embodiment

[0030] FIG. **1** is an exploded perspective view of a piezoelectric device **100**. The piezoelectric device **100** includes a lid plate **110**, a base plate **120**, and a piezoelectric vibration element **130**. The piezoelectric vibration element **130** employs, for example, an AT-cut crystal resonator. The AT-cut crystal resonator has a principal surface (in the Y-Z plane) that is tilted by 35° 15' about the Y-axis of crystallographic axes (XYZ) in the direction from the Z-axis to the Y-axis around the X-axis. In the following description, the new axes tilted with reference to the axis directions of the AT-cut crystal resonator are denoted as the Y'-axis and the Z'-axis. This disclosure defines the long side direction of the piezoelectric device **100** as the X-axis direction, the height direction of the piezoelectric device **100** as the Y'-axis direction, and the direction perpendicular to the X and Y'-axis directions as the Z'-axis direction.

[0031] The piezoelectric vibration element **130** includes a piezoelectric piece **134** with a mesa portion **133**, an excitation electrode **131**, and an extraction electrode **132**. The piezoelectric piece **134** vibrates at a predetermined frequency and has a rectangular shape. The protruded mesa portions **133** are formed on the principal surfaces of the piezoelectric piece **134** at the +Y'-axis side and the −Y'-axis side. The excitation electrode **131** is formed on the whole area and at the peripheral area of the mesa portion **133**. The extraction electrode **132** is extracted from each excitation electrode **131** to the −X-axis side. The extraction electrode **132** is extracted from the excitation electrode **131**, which is formed on the surface at the +Y'-axis side of the piezoelectric piece **134**, and the extraction electrode **132** is extracted from the excitation electrode **131** to the −X-axis side, and is further extracted to the surface at the −Y'-axis side of the piezoelectric piece **134** via the side surface at the −Z'-axis side of the piezoelectric piece **134**. The extraction electrode **132** is extracted from the excitation electrode **131**, which is formed on the surface at the −Y'-axis side of the piezoelectric piece **134**, and the extraction electrode **132** is extracted from the excitation electrode **131** to the −X-axis side, and is further extracted to the surface at the +Y'-axis side of the piezoelectric piece **134** via the side surface at the +Z'-axis side of the piezoelectric piece **134**.

[0032] A bonding surface **122** is formed at the peripheral area of the surface at the +Y'-axis side of the base plate **120**. The bonding surface **122** is to be bonded to the lid plate **110** via a sealing material **142** (see FIG. **2**). The base plate **120** includes a depressed portion **121** at the center of the surface at the +Y'-axis side. The depressed portion **121** is depressed from the bonding surface **122** in the −Y'-axis direction. A pair of connecting electrodes **123** is formed in the depressed portion **121**. Each connecting electrode **123** electrically connects to an extraction electrode **132** of the piezoelectric vibration element **130** via a conductive adhesive **141** (see FIG. **2**). The base plate **120** includes a pair of external electrodes **126** on the surface at the −Y'-axis side. The external electrode **126** electrically connects to the connecting electrode **123** with a through electrode **124** that passes through the base plate **120**.

[0033] The lid plate **110** includes a depressed portion **111** on the surface at the −Y'-axis side. The depressed portion **111** is depressed in the +Y'-axis direction. A bonding surface **112** is formed surrounding the depressed portion **111**. The bonding surface **112** is bonded to the bonding surface **122** of the base plate **120** via the sealing material **142** (see FIG. **2**).

[0034] FIG. **2** is a cross-sectional view taken along the line I-I of FIG. **1**. A cavity **101** is sealed in the piezoelectric device **100**. With the piezoelectric device **100**, the cavity **101** is formed by bonding the bonding surface **122** of the base plate **120** and the bonding surface **112** of the lid plate **110** together via the sealing material **142**. The piezoelectric vibration element **130** is disposed in the cavity **101**. The piezoelectric vibration element **130** includes the excitation electrode **131**. A piezoelectric piece **134** includes the mesa portion **133**. The thickness of the mesa portion **133** in the Y'-axis direction is thicker than the thickness of a peripheral portion **135** that surrounds the mesa portion **133** in the Y'-axis direction. The piezoelectric vibration element **130** is formed by bonding the extraction electrode **132** and the connecting electrode **123** of the base plate **120** together via the conductive adhesive **141**. The piezoelectric vibration element **130** is disposed in the cavity **101**. Additionally, the extraction electrode **132** electrically connects to the connecting electrode **123** via the conductive adhesive **141**. This electrically connects the excitation electrode **131** and an external electrode **126** together.

[0035] FIG. **3** is a plan view of the piezoelectric vibration element **130**. The piezoelectric vibration element **130** includes the rectangular piezoelectric piece **134** that has a long side in the X-axis direction and the short side in the Z'-axis direction. The piezoelectric piece **134** includes the rectangular excitation electrodes **131** on the surfaces at the +Y'-axis side and the −Y'-axis side. The excitation electrodes **131**, which are formed on the surfaces at the +Y'-axis side and the −Y'-axis side, mutually have the same shape and the same dimensions and symmetrically formed in the X-Z' plane. The piezoelectric piece **134** includes the mesa portions **133** on the surfaces at the +Y'-axis side and the −Y'-axis side. The surface of the mesa portion **133** is covered with the excitation electrode **131**. The extraction electrode **132** is extracted from each excitation electrode **131** in the −X-axis direction.

[0036] Assume that a length of the piezoelectric piece in the X-axis direction (a length of the long side) is length AX, and a length of the piezoelectric piece in the Z'-axis direction (a length of the short side) is length AZ. Then, the piezoelectric vibration element **130** has the length AX of 1.355 mm and the length AZ of 0.795 mm. The following denotes a length of the excitation electrode in the X-axis direction as a length RX, a length of the excitation electrode in the Z'-axis direction as a length RZ, a length of the mesa portion in the X-axis direction as a length MX, and a length of the mesa portion in the Z'-axis direction as a length MZ. Further, the following will be assumed. The center of the surface at the +Y'-axis side of the piezoelectric piece **134** is a center CA. The center of the excitation electrode **131** formed on the surface at the +Y'-axis side is a center CR. The center of the mesa portion **133** formed at the +Y'-axis side is a center CM. A distance between the center CA and the center CR is a first distance DR. A distance between the center CA and the center CM is a second distance

DM. Then, the first distance DR and the second distance DM described below are expressed as a negative value when the center CR and the center CM are closer to the −X-axis side than the center CA. The first distance DR and the second distance DM are expressed as a positive value when the center CR and the center CM are closer to the +X-axis side than the center CA. Further, the center CA, the center CR, and the center CM are on a straight line **171** parallel to the X-axis.

Simulation Result of the Piezoelectric Vibration Element **130**

[0037] The appropriate formation position, shape, and size of the mesa portion **133** and the excitation electrode **131** of the piezoelectric vibration element **130** were examined by simulation. A description will be given of the simulation result.

Stress Applied to the Piezoelectric Vibration Element

[0038] FIG. **4**A is a plan view of a piezoelectric vibration element **130***a*. The piezoelectric vibration element **130***a* includes mesa portions **133***a* on the surfaces at the +Y'-axis side and the −Y'-axis side. Conductive adhesives **141***a* are formed on the surface at the −Y'-axis side of the piezoelectric vibration element **130***a*. The conductive adhesives **141***a* are formed at each corner portion of the −X-axis side and the +Z'-axis side, and the −X-axis side and the −Z'-axis side on the surface. The piezoelectric vibration element **130***a* was employed for a simulation of stress applied to a piezoelectric vibration element.

[0039] FIG. **4**B is a plan view of the piezoelectric vibration element **130***a* where a simulation result of stress distribution at a drop of the piezoelectric device is illustrated. A simulation of dropping the piezoelectric device was performed assuming that acceleration of 3000 G was taken in the Y'-axis direction. FIG. **4**B illustrates a strength of stress applied to the piezoelectric vibration element **130***a* by a drop in nine incremental values. The region indicated by a color close to white means that the weakest stress (0~1) is applied to the piezoelectric vibration element **130***a*. The black region means that the strongest stress (8~9) is applied to the piezoelectric vibration element **130***a*. It can be seen from FIG. **4**B that stress applied to the periphery of the end portion at the +X-axis side of the piezoelectric vibration element **130***a*, which is the furthest from the formation position of the conductive adhesive **141***a*, is the smallest.

[0040] FIG. **4**C is a plan view of the piezoelectric vibration element **130***a* where a simulation result of stress distribution at a temperature change of the piezoelectric device is illustrated. A simulation of changing temperature of the piezoelectric device was performed assuming that the temperature of the piezoelectric device was reduced from 400° C. to 25° C. FIG. **4**C illustrates a strength of stress applied to the piezoelectric vibration element **130***a* by temperature change in nine incremental values. The region indicated by a color close to white means that the weakest stress (0~1) is applied to the piezoelectric vibration element **130***a*. The black region means that the strongest stress (8~9) is applied to the piezoelectric vibration element **130***a*. It can be seen from FIG. **4**C that a change in stress affected by a temperature change becomes small as the region is away from the region where the conductive adhesive **141***a* is formed.

[0041] Stress generated in the piezoelectric vibration element may shift a vibration frequency of the piezoelectric vibration element. Further, the conductive adhesive may be deformed by stress once applied by a drop or similar cause. This leaves the vibration frequency of the piezoelectric vibration element shifted. It can be seen from FIGS. **4**B and **4**C that a position away from the position where the conductive adhesive is formed is less affected by stress generated by a drop and a temperature change. Accordingly, to prevent a vibration frequency from being shifted by stress caused by a drop, a temperature change, or similar cause, it is preferred that the mesa portion, which is the main region where a vibration frequency of the piezoelectric vibration element is generated, be disposed at a position away from the conductive adhesive.

Relationship Among Dimensions of the Mesa Portion and the Excitation Electrode and the Mesa Portion

[0042] FIG. **5** is a circuit diagram illustrating an equivalent circuit of the piezoelectric vibration element. The piezoelectric vibration element can be expressed as an equivalent circuit as illustrated in FIG. **5**. FIG. **5** indicates an equivalent series inductance as L1, an equivalent series capacitance as C1, an equivalent series resistance as R1, and a shunt capacitance as C0. R1 indicates a loss component, such as an internal friction and an acoustic loss of vibration energy during vibration. The R1 value corresponds to crystal impedance (CI) of the piezoelectric vibration element. Therefore, it is preferred that the R1 value be small. The C1 is a value that indicates flexibility and plasticity of the piezoelectric vibration element. The larger the C1 is, the stronger the plasticity of the piezoelectric vibration element is, and this condition is preferred. The following describes evaluation of C1s and R1s of the piezoelectric vibration element **130***b* and the piezoelectric vibration element **130***c* by simulation. This finds suitable relationship among dimensions of the mesa portion, the excitation electrode, and the mesa portion.

[0043] FIG. **6**A is a plan view of the piezoelectric vibration element **130***b*. The piezoelectric vibration element **130***b* includes the mesa portion **133** on the surfaces at the +Y'-axis side and the −Y'-axis side. The excitation electrode **131** is formed to cover the mesa portion **133**. The piezoelectric vibration element **130***b* has the length AX of 1.355 mm, the length AZ of 0.795 mm, the length RX of 0.89 mm, the length RZ of 0.64 mm, the length MZ of 0.6 mm, and the second distance DM of 0.045 mm. Conductive adhesives **141***b* are formed on the surface at the −Y'-axis side of the piezoelectric piece **134**. The conductive adhesives **141***b* are formed at the −X-axis side and the +Z'-axis side, and the −X-axis side and the −Z'-axis side on the surface. The conductive adhesive **141***b* has a length SX in the X-axis direction of 0.215 mm and a length SZ in the Z'-axis direction of 0.22 mm.

[0044] FIG. **6**B is a plan view of the piezoelectric vibration element **130***c*. The piezoelectric vibration element **130***c* includes the mesa portions **133** on the surfaces at the +Y'-axis side and the −Y'-axis side. An excitation electrode **131***c* is formed on the surface of the mesa portion **133**. The conductive adhesives **141***b* are formed on the surface at the −Y'-axis side of the piezoelectric piece **134**. The conductive adhesives **141***b* are formed at the −X-axis side and the +Z'-axis side, and the −X-axis side and the −Z'-axis side on the surface. The piezoelectric vibration element **130***c* has lengths AX, AZ, MZ, SX, SZ, and a second distance DM that are same values with the piezoelectric vibration element **130***b*. The length RZ of the excitation electrode **131***c* is formed to be 0.5 mm. The length RX is formed such that the length is equal to the value where 0.1 mm is subtracted from the length MX of the mesa portion **133**. In short, the excitation electrode **131***c* includes an outer periphery of the excitation electrode **131***c* inside of

the outer periphery side of the mesa portion **133** by 0.05 mm. The area of the excitation electrode **131***c* becomes narrower than an area of the excitation electrode **131**.

[0045] FIG. **7**A is a graph illustrating a relationship between a length MX of the mesa portion **133** in the X-axis direction and the equivalent series capacitance C1. In FIG. **7**A, the white triangle indicates the result of the piezoelectric vibration element **130***b*, and the cross mark indicates the result of the piezoelectric vibration element **130***c*. In FIG. **7**A, the horizontal axis indicates the length MX of the mesa portion in the X-axis direction, and the vertical axis indicates the value of the equivalent series capacitance C1. In FIG. **7**A, the piezoelectric vibration element **130***b* has C1 of approximately 1.2 fF when the length MX is 0.35 mm and C1 of approximately 2.0 fF when the length MX is 1 mm. The piezoelectric vibration element **130***c* has C1 of approximately 0.7 fF when the length MX is 0.5 mm and C1 of approximately 1.7 fF when the length MX is 1.0 mm. In FIG. **7**A, C1 values of both the piezoelectric vibration element **130***b* and the piezoelectric vibration element **130***c* tend to be high as the length MX of the mesa portion **133** in the X-axis direction becomes long. That is, the larger the area of the mesa portion **133** is, the higher the C1 value is, and this condition is preferred. And, the C1 value of the piezoelectric vibration element **130***b* is always higher than the C1 value of the piezoelectric vibration element **130***c* in the length MX of the mesa portion **133** in the X-axis direction. The piezoelectric vibration element **130***b* differs from the piezoelectric vibration element **130***c* in the area of the excitation electrode. It is considered that the C1 value is higher, because the area of the excitation electrode **131** of the piezoelectric vibration element **130***b* is larger than the area of the excitation electrode **131***c* of the piezoelectric vibration element **130***c*. Therefore, it is considered that the area of the excitation electrode is preferred to be large.

[0046] FIG. **7**B is a graph illustrating a relationship between a length MX of the mesa portion **133** in the X-axis direction and the equivalent series resistance R1. In FIG. **7**B, the white triangle indicates the result of the piezoelectric vibration element **130***b*, and the cross mark indicates the result of the piezoelectric vibration element **130***c*. In FIG. **7**B, the horizontal axis indicates the length MX of the mesa portion **133** in the X-axis direction, and the vertical axis indicates the value of the equivalent series resistance R1. In FIG. **7**B, the piezoelectric vibration element **130***b* has R1 of approximately 87Ω when the length MX is 0.35 mm and R1 of approximately 46Ω when the length MX is 1.0 mm. The piezoelectric vibration element **130***c* has R1 of approximately 150Ω when the length MX is 0.5 mm and R1 of approximately 75Ω when the length MX is 1.0 mm. It can be seen from 7B that R1 values of both the piezoelectric vibration element **130***b* and the piezoelectric vibration element **130***c* become low as the length MX of the mesa portion **133** in the X-axis direction becomes long. That is, the larger the area of the mesa portion **133** is, the lower the R1 value is, and this condition is preferred. When the lengths MX of the mesa portion **133** in the X-axis direction are the same, the R1 value of the piezoelectric vibration element **130***b* is always lower than the R1 value of the piezoelectric vibration element **130***c*. It is considered that the R1 value is lower, because the area of the excitation electrode **131** of the piezoelectric vibration element **130***b* is larger than the area of the excitation electrode **131***c* of the piezoelectric vibration element **130***c*. Therefore, it is considered that the area of the excitation electrode is preferred to be large.

[0047] It can be seen from FIGS. **7**A and **7**B that the larger the area of the mesa portion **133** is, the higher the C1 is, and the lower the R1 is, and this condition is preferred. Additionally, the larger the area of the excitation electrode is, the higher the C1 is, and the lower the R1 is, and this condition is preferred. With the piezoelectric vibration element **130**, to form the large area of the excitation electrode, the center CR of the excitation electrode is close to the center CA of the piezoelectric piece **134**. Considering that the extraction electrode **132** is to be formed on the side at the −X-axis side of the piezoelectric piece **134**, it is preferred that the center CR of the excitation electrode **131** be formed at a position slightly toward the +X-axis side from the center CA of the piezoelectric piece **134**. The mesa portion **133** is less stressed when it is disposed close to the +X-axis side of the piezoelectric piece **134**, and this condition is preferred. Therefore, it is preferred that the center CM of the mesa portion **133** be disposed closer to the +X-axis side than the center CR of the excitation electrode **131** and the center CA of the piezoelectric piece **134**.

Formation Position of the Mesa Portion

[0048] FIG. **8** is a table listing dimensions of the excitation electrode and dimensions of the mesa portion of the piezoelectric vibration element. The following describes a preferred position of the mesa portion relative to the piezoelectric vibration element by simulation of the piezoelectric vibration elements listed in FIG. **8**. FIG. **8** lists four piezoelectric vibration elements: the piezoelectric vibration element **130***d*, a piezoelectric vibration element **130***e*, a piezoelectric vibration element **130***f*, and a piezoelectric vibration element **130***g*. The piezoelectric vibration element **130***d* and the piezoelectric vibration element **130***e* have the excitation electrodes and the mesa portions with the same dimensions. They differ only in the first distance DR, which is a distance between the center of the excitation electrode and the center of the piezoelectric vibration element. The piezoelectric vibration element **130***f* and the piezoelectric vibration element **130***g* differ only in the length MX of the mesa portion in the X-axis direction. Further, the piezoelectric vibration elements **130***d* and **130***e* mainly differ from the piezoelectric vibration elements **130***f* and **130***g* in a length RX of the excitation electrode in the X-axis direction.

[0049] FIG. **9**A is a graph illustrating a relationship between the second distance DM and the equivalent series capacitance C1. In FIG. **9**A, the horizontal axis indicates the second distance DM, and the vertical axis indicates the equivalent series capacitance C1. FIG. **9**A also illustrates the relationship between the second distance DM and the equivalent series capacitance C1 of the four piezoelectric vibration elements listed in FIG. **8**. In FIG. **9**A, the white diamond indicates the piezoelectric vibration element **130***d*, the white triangle indicates the piezoelectric vibration element **130***e*, the black square indicates the piezoelectric vibration element **130***f*, and the black circle indicates the piezoelectric vibration element **130***g*.

[0050] It is a tendency that a C1 change relative to the second distance DM is similar between the piezoelectric vibration element **130***d* and the piezoelectric vibration element **130***e*. Additionally, it is a tendency that the C1 increases as the second distance DM increases until the second distance

DM changes close to −0.1 mm. In the case where the second distance DM value is larger than −0.1 mm, the C1 is stable at a value close to approximately 1.3 fF, regardless of the second distance DM value. Therefore, the piezoelectric vibration element **130***d* and the piezoelectric vibration element **130***e* have a high C1 value when the second distance DM is larger than −0.1 mm, and this condition is preferred. Both the piezoelectric vibration element **130***d* and the piezoelectric vibration element **130***e* exhibit similar tendency; therefore, it is considered that the formation position of the excitation electrode **131** does not affect the C1 so much.

[0051] With the piezoelectric vibration element **130***f*, the C1 increases as the second distance DM increases until the second distance DM reaches −0.1 mm. When the second distance DM is between −0.1 mm and 0.2 mm, the C1 is stable between approximately 1.5 fF and approximately 1.7 fF. When the second distance DM is equal to or more than 0.2 mm, the C1 reduces as the second distance DM increases. Therefore, the piezoelectric vibration element **130***f* has a high C1 value when the second distance DM is between −0.1 mm and 0.2 mm, and this condition is preferred.

[0052] With the piezoelectric vibration element **130***g*, when the second distance DM is equal to or less than 0 mm, the C1 increases as the second distance DM increases. When the second distance DM is between 0 mm and 0.2 mm, the C1 is stable between approximately 1.9 fF and approximately 2.1 fF. When the second distance DM is equal to or more than 0.2 mm, the C1 reduces as the second distance DM increases. Therefore, the piezoelectric vibration element **130***g* has a high C1 value when the second distance DM is between 0 mm and 0.2 mm, and this condition is preferred.

[0053] FIG. **9**A shows a tendency that the C1 value of the piezoelectric vibration element **130***g* is higher than the C1 value of the piezoelectric vibration element **130***f*. The piezoelectric vibration element **130***f* differs from the piezoelectric vibration element **130***g* in the area of the mesa portion **133**; therefore, it is considered that the larger the area of the mesa portion **133** is, the higher the C1 value is. This is consistent with the fact that the C1 values of the piezoelectric vibration element **130***d* and the piezoelectric vibration element **130***e*, which have narrower areas of the mesa portion **133** than areas of the piezoelectric vibration element **130***f* and the piezoelectric vibration element **130***g*, are lower than the C1 values of the piezoelectric vibration element **130***f* and the piezoelectric vibration element **130***g*.

[0054] With the piezoelectric vibration element **130***f* and the piezoelectric vibration element **130***g*, the C1 becomes extremely low after the second distance DM value exceeds 0.2 mm. This is probably because if the mesa portion **133** is too close to the end portion of the piezoelectric vibration element, the mesa portion **133** does not serve well for a vibration. All the piezoelectric vibration elements **130***d*, **130***e*, **130***f*, and **130***g* have high C1 when the second distance DM is within the range of 0 mm to 0.2 mm. It is considered that the piezoelectric vibration element with the second distance DM within this range is preferable. As illustrated in FIGS. **4**B and **4**C, the vibrating region of the piezoelectric vibration element is preferably disposed at a position far from the conductive adhesive and close to the end of the +X-axis side since such position is less stressed. Therefore, the appropriate position of the center CM of the mesa portion **133** is a position where the second distance DM is within a range of 0 mm to 0.2 mm. The more preferred position is a position where the second distance DM is between 0.1 and 0.2 mm, in which the center CM of the mesa portion **133** is more close toward the +X-axis side. Considering a length ratio between the second distance DM and the length AX of the long side of the piezoelectric vibration element **130***f*, it is preferred that the second distance DM be within the range between 0.1 mm and 0.2 mm when the length AX is 1.355 mm. Therefore, it is preferred that the second distance DM be 0.073 to 0.148 times of the length AX.

[0055] FIG. **9**B is a graph illustrating a relationship between the second distance DM and the equivalent series resistance R1. FIG. **9**B also illustrates the relationship between the equivalent series resistance R1 and the second distance DM of the four piezoelectric vibration elements listed in FIG. **8**. In FIG. **9**B, similarly to FIG. **9**A, the white diamond indicates the piezoelectric vibration element **130***d*, the white triangle indicates the piezoelectric vibration element **130***e*, the black square indicates the piezoelectric vibration element **130***f*, and the black circle indicates the piezoelectric vibration element **130***g*. It is a similar tendency for both the piezoelectric vibration element **130***d* and the piezoelectric vibration element **130***e*: in the case where the second distance DM is larger than −0.2 mm, the R1 is stable at a low value close to approximately 80Ω, and this condition is preferred. With the piezoelectric vibration element **130***f* and the piezoelectric vibration element **130***g*, the R1 becomes low when the second distance DM is −0.1 mm to 0.25 mm and 0 mm to 0.2 mm, and this condition is preferred.

[0056] Similarity to FIG. **9**A, a cause of respective different R1s among the piezoelectric vibration elements **130***d*, **130***e*, **130***f*, and **130***g* is associated with the area of the mesa portion **133**. With the piezoelectric vibration element **130***f*, the R1 becomes large when the second distance DM exceeds 0.25 mm. With the piezoelectric vibration element **130***g*, the R1 becomes large when the second distance DM exceeds 0.2 mm. This is probably because if the mesa portion **133** is too close to the end portion of the piezoelectric vibration element, the mesa portion **133** does not serve well for a vibration. Similarly to FIG. **9**A, all the piezoelectric vibration elements **130***d*, **130***e*, **130***f*, and **130***g* have low R1 when the second distance DM is from 0 mm to 0.2 mm. As illustrated in FIGS. **4**B and **4**C, the vibrating region of the piezoelectric vibration element is preferably disposed at a position far from the conductive adhesive and close to the end of the +X-axis side since such position is less stressed. Therefore, the appropriate position of the center CM of the mesa portion **133** is a position where the second distance DM is within a range of 0 mm to 0.2 mm. The more preferred position is a position where the second distance DM is between 0.1 and 0.2 mm, in which the center CM of the mesa portion **133** is more close toward the +X-axis side. Similarly to FIG. **9**A, it is preferred that the second distance DM be 0.073 to 0.148 times of the length AX.

Second Embodiment

[0057] A piezoelectric vibration element may include a framing portion that surrounds a piezoelectric piece. A description will be given of a piezoelectric vibration element **230** with the framing portion and a piezoelectric device **200** with the piezoelectric vibration element **230**. Like reference numerals designate corresponding or identical elements throughout Embodiments 1 and 2, and therefore such elements will not be further elaborated here.

Constitution of the Piezoelectric Device **200**

[0058] FIG. **10** is an exploded perspective view of the piezoelectric device **200**. The piezoelectric device **200**

includes a piezoelectric vibration element **230**, a base plate **220**, and a lid plate **110**. The piezoelectric vibration element **230** includes a piezoelectric piece **234** and a framing portion **235**, which surrounds the piezoelectric piece **234**. The base plate **220** and the lid plate **110** are bonded together with sandwiching the framing portion **235**, thus the piezoelectric device **200** is formed.

[0059] The piezoelectric vibration element **230** is formed of the piezoelectric piece **234** and the framing portion **235**. The piezoelectric piece **234** connects to the framing portion **235** at the −X-axis side. The piezoelectric piece **234** includes a mesa portion **233**. Excitation electrodes **231** are formed at the mesa portion **233** and the peripheral area of the mesa portion **233**. An extraction electrode **232** is extracted from the excitation electrode **231** to the framing portion **235**.

[0060] A bonding surface **222** is formed at the peripheral area on the surface at the +Y'-axis side of the base plate **220**. The bonding surface **222** is to be bonded to the framing portion **235** via a sealing material **141** (see FIG. **11**). The base plate **220** includes a depressed portion **221** at the center of the surface at the +Y'-axis side. The depressed portion **221** is depressed from the bonding surface **222** in the −Y'-axis direction. The base plate **220** includes connecting electrodes **223** at four corners on the bonding surface **222**. An extraction electrode **232** of the piezoelectric vibration element **230** electrically connects to the connecting electrode **223**. The base plate **220** includes castellations **225** at four corners on the side surfaces. The castellation **225** is depressed toward inside of the base plate **220**. Each castellation **225** includes a side surface electrode **224** on its side surface. A pair of external electrodes **226** is disposed on the surface at the −Y'-axis side of the base plate **220**. The external electrode **226** electrically connects to the connecting electrode **223** via the side surface electrode **224**.

[0061] FIG. **11** is a cross-sectional view taken along the line II-II of FIG. **10**. With the piezoelectric device **200**, the lid plate **110** is bonded on the surface at the +Y'-axis side of the framing portion **235** of the piezoelectric vibration element **230** via the sealing material **141**. The base plate **220** is bonded on the surface at the −Y'-axis side of the framing portion **235** via the sealing material **141**. This forms a cavity **201** in the piezoelectric device **200**, and the piezoelectric piece **234** of the piezoelectric vibration element **230** is sealed in the cavity **201**.

[0062] The piezoelectric vibration element **230** includes the mesa portions **233** on the surfaces at the +Y'-axis side and the −Y'-axis side. The excitation electrode **231** is formed to cover the mesa portion **233**. The extraction electrode **232** is extracted from the excitation electrode **231** to the surface at the −Y'-axis side of the framing portion **235**. The extraction electrode **232** electrically connects to the connecting electrode **223** of the base plate **220**. Since the connecting electrode **223** electrically connects to the external electrode **226** via the side surface electrode **224**, the excitation electrode **231** electrically connects to the external electrode **226**.

[0063] FIG. **12** is a plan view of the piezoelectric vibration element **230**. The piezoelectric vibration element **230** includes the piezoelectric piece **234** and the framing portion **235**. The piezoelectric piece **234** connects to the framing portion **235** at the side of the −X-axis side. Between the piezoelectric piece **234** and the framing portion **235**, through grooves **236** are formed. The through grooves **236** penetrate the piezoelectric vibration element **230** in the Y'-axis direction. The through grooves **236** are formed at the center of the −X-axis side, at the +X-axis side, at the +Z'-axis side, and at the −Z'-axis side of the piezoelectric piece **234**. Therefore, the piezoelectric piece **234** connects to the framing portion **235** at two portions: at the end portions on the side of the −X-axis side at the +Z'-axis side, and at the −Z'-axis side of the piezoelectric piece **234**. The two portions, where this piezoelectric piece **234** connects to the framing portion **235**, are referred to as connecting portions **237**.

[0064] The piezoelectric piece **234** of the piezoelectric vibration element **230** includes the mesa portions **233** on the surfaces at the +Y'-axis side and the −Y'-axis side. The excitation electrode **231** is formed in the piezoelectric piece **234** to cover the mesa portion **233**. From the excitation electrode **231** formed on the surface at the +Y'-axis side of the piezoelectric piece **234**, the extraction electrode **232** is extracted to the corner of the −X-axis side and the +Z'-axis side of the framing portion **235** via the side surface at the +Z'-axis side and the connecting portion **237** at the +Z'-axis side of the piezoelectric piece **234**. From the excitation electrode **231** formed on the surface at the −Y'-axis side, the extraction electrode **232** is extracted to the corner of the +X-axis side and the −Z'-axis side of the framing portion **235** via the connecting portion **237** at the −Z'-axis side.

Simulation Result of the Piezoelectric Vibration Element **230***a*

[0065] The appropriate formation position, shape, and size of the mesa portion **233** of the piezoelectric vibration element **230** were examined by simulation. A description will be given of the simulation result.

Stress and Temperature Dependence

[0066] FIG. **13**A is a plan view of the piezoelectric vibration element **230***a*. The piezoelectric vibration element **230***a* was employed for the simulation. The piezoelectric vibration element **230***a* includes the mesa portion **233** on the surfaces at the +Y'-axis side and the −Y'-axis side. The piezoelectric piece **234** connects to the framing portion **235** via the connecting portions **237** at the end portion at the side of the −X-axis side at the +Z'-axis side and the −Z'-axis side of the piezoelectric vibration element **230***a*.

[0067] FIG. **13**B is a plan view of the piezoelectric vibration element **230***a* where a simulation result of stress distribution at a drop of the piezoelectric device is illustrated. A simulation of dropping the piezoelectric device was performed assuming that acceleration of 3000G was taken in the Y'-axis direction. FIG. **13**B illustrates a strength of stress applied to the piezoelectric vibration element **230***a* by a drop in nine incremental values. The region indicated by a color close to white means that the weakest stress (0~1) is applied to the piezoelectric vibration element **230***a*. The black region means that the strongest stress (8~9) is applied to the piezoelectric vibration element **230***a*. It can be seen from FIG. **13**B that stress applied in the piezoelectric piece **234** becomes small at the +X-axis side of the piezoelectric piece **234**. Therefore, it is preferred that the mesa portion **233** where a vibration is generated be formed at the +X-axis side of the piezoelectric piece **234**.

[0068] FIG. **13**C is a plan view of the piezoelectric vibration element **230***a* where a simulation result of stress distribution at a temperature change of the piezoelectric device is illustrated. A simulation of changing temperature of the piezoelectric device was performed assuming that the tem-

perature of the piezoelectric device was reduced from 400° C. to 25° C. FIG. **13**C illustrates a strength of stress applied to the piezoelectric vibration element **230***a* by temperature change in nine incremental values. The region indicated by a color close to white means that the weakest stress (0~1) is applied to the piezoelectric vibration element **230***a*. The black region means that the strongest stress (8~9) is applied to the piezoelectric vibration element **230***a*. FIG. **13**C illustrates regions close to the connecting portions **237** of the framing portion **235** and the piezoelectric piece **234** in black. This shows that strong stress is applied to these regions. The farther a distance between the piezoelectric piece **234** and the connecting portion **237** is, the smaller the stress is. Hence, it is assumed that a change in stress affected by a temperature change becomes the smallest at a periphery of the end portion at the +X-axis side of the piezoelectric piece **234**.

[0069] In FIGS. **13**B and **13**C, stress becomes the smallest at a region farthest from the connecting portions **237**. Accordingly, with the piezoelectric vibration element, the closer the mesa portion **233** is to the +X-axis side, the less a frequency variation caused by stress is. The −X-axis side of the piezoelectric piece **134** is secured with the conductive adhesive. Similarly, the piezoelectric piece **234** is secured to the framing portion **235** at the side at the −X-axis side via the connecting portion **237**. Similarly to Embodiment 1, it is considered to be preferable that the second distance DM be 0.073 to 0.148 times of the length AX.

[0070] Representative embodiments are described in detail above; however, as will be evident to those skilled in the relevant art, this disclosure may be changed or modified in various ways within its technical scope.

[0071] For example, the first Embodiment and the second Embodiment disclose the mesa portions disposed on the both principal surfaces at the +Y'-axis side and the −Y'-axis side; however, the mesa portion may be formed on only either one of the principal surfaces. Additionally, the above-described embodiments disclose a case where the piezoelectric piece is an AT-cut crystal wafer. A BT-cut crystal wafer or similar member that similarly vibrates in the thickness-shear mode is similarly applicable. Further, the piezoelectric piece is basically applicable to a piezoelectric material that includes not only quartz-crystal material but also lithium tantalite, lithium niobate, and piezoelectric ceramic.

[0072] In the piezoelectric vibration element according to the first aspect, a second aspect may be constituted as follows. The second distance may be 0.073 to 0.148 times of a length of the long side.

[0073] In the piezoelectric vibration element according to the first aspect and the second aspect, a third aspect may further include a framing portion that surrounds the piezoelectric piece. The framing portion connects to the one short side of the piezoelectric piece. The pair of extraction electrodes is further extracted from the one short side to the framing portion.

[0074] A fourth aspect is a piezoelectric device that includes the piezoelectric vibration element according to the first aspect to the third aspect, a base plate where the piezoelectric vibration element is placed, and a lid plate that seals the piezoelectric piece.

[0075] With the piezoelectric vibration element and the piezoelectric device according to the embodiments, a frequency variation caused by impact such as a drop and temperature change can be less generated. This ensures the improved vibration characteristic.

[0076] The principles, preferred embodiment and mode of operation of the present invention have been described in the foregoing specification. However, the invention which is intended to be protected is not to be construed as limited to the particular embodiments disclosed. Further, the embodiments described herein are to be regarded as illustrative rather than restrictive. Variations and changes may be made by others, and equivalents employed, without departing from the spirit of the present invention. Accordingly, it is expressly intended that all such variations, changes and equivalents which fall within the spirit and scope of the present invention as defined in the claims, be embraced thereby.

What is claimed is:

1. A piezoelectric vibration element, comprising:

a piezoelectric piece that has a rectangular shape with long sides and short sides, the piezoelectric piece including a first principal surface and a second principal surface, the second principal surface being a backside surface of the first principal surface, the piezoelectric piece including a mesa portion at least on the first principal surface, the mesa portion being thicker than a peripheral portion;

a pair of excitation electrodes, formed on the first principal surface and the second principal surface; and

a pair of extraction electrodes, extracted from the pair of excitation electrodes to one of the short sides, wherein

the excitation electrode is larger than an area of the mesa portion and covers the mesa portion on the principal surface where the mesa portion is formed,

the excitation electrode has a center away from a center of the piezoelectric piece toward another short side by a first distance, and

the mesa portion has a center away from the center of the piezoelectric piece to the other short side by a second distance, and

the second distance is different from the first distance.

2. The piezoelectric vibration element according to claim **1**, wherein

the second distance is 0.073 to 0.148 times of a length of the long side.

3. The piezoelectric vibration element according to claim **1**, further comprising:

a framing portion that surrounds the piezoelectric piece,

the framing portion being connected to the one short side of the piezoelectric piece; and

the pair of extraction electrodes that is further extracted from the one short side to the framing portion.

4. A piezoelectric device, comprising:

the piezoelectric vibration element according to claim **1**;

a base plate where the piezoelectric vibration element is placed; and

a lid plate that seals the piezoelectric piece.

* * * * *