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(54) **PIEZOELECTRIC DEVICE**

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(57) **ABSTRACT**

The piezoelectric device (**100**) stores a piezoelectric vibrating piece (**10**) which vibrates whenever an electrical voltage is applied. The piezoelectric device comprises: a package lid (**11**) having a first peripheral surface (M**1**) which surrounds a plane surface in a predetermined width; and a package base (**12**) comprising a second peripheral surface (M**2**) bonded to the first peripheral surface of the package lid and a recess portion recessed from the second peripheral surface. The first peripheral surface of the package lid and the second peripheral surface of the package base are rough surfaces, respective metal films (AC**1**, AC**2**) are formed on each rough surface, and the package lid and the package base are bonded using a sealing material (LG) formed between the metal films.

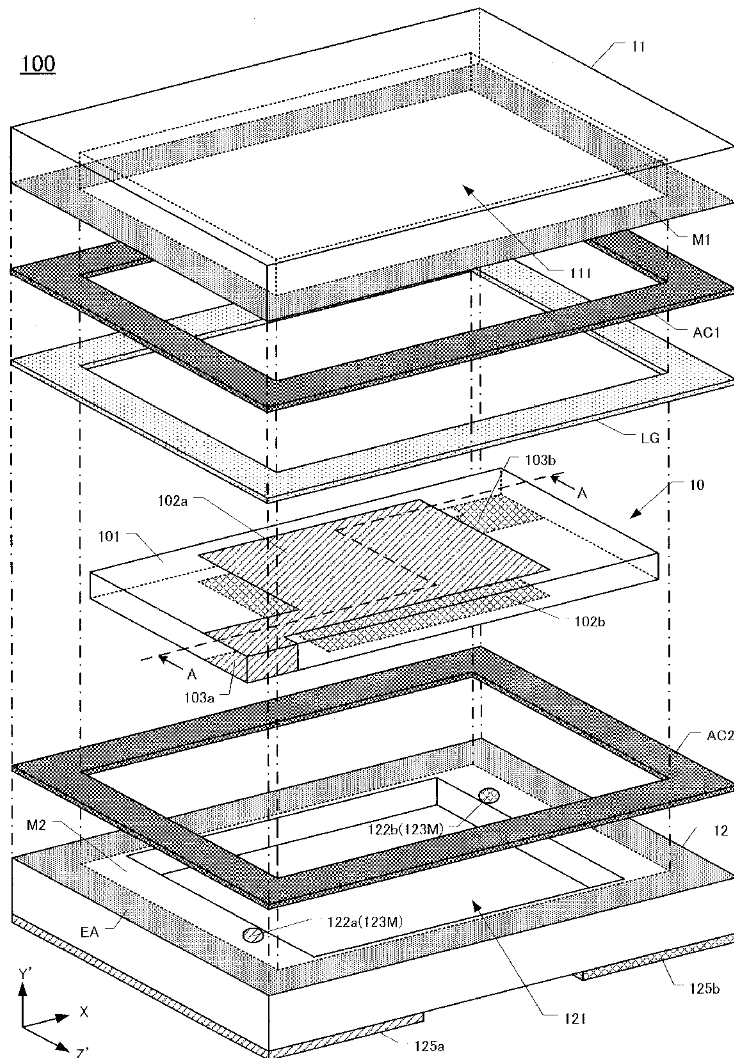


Fig. 1

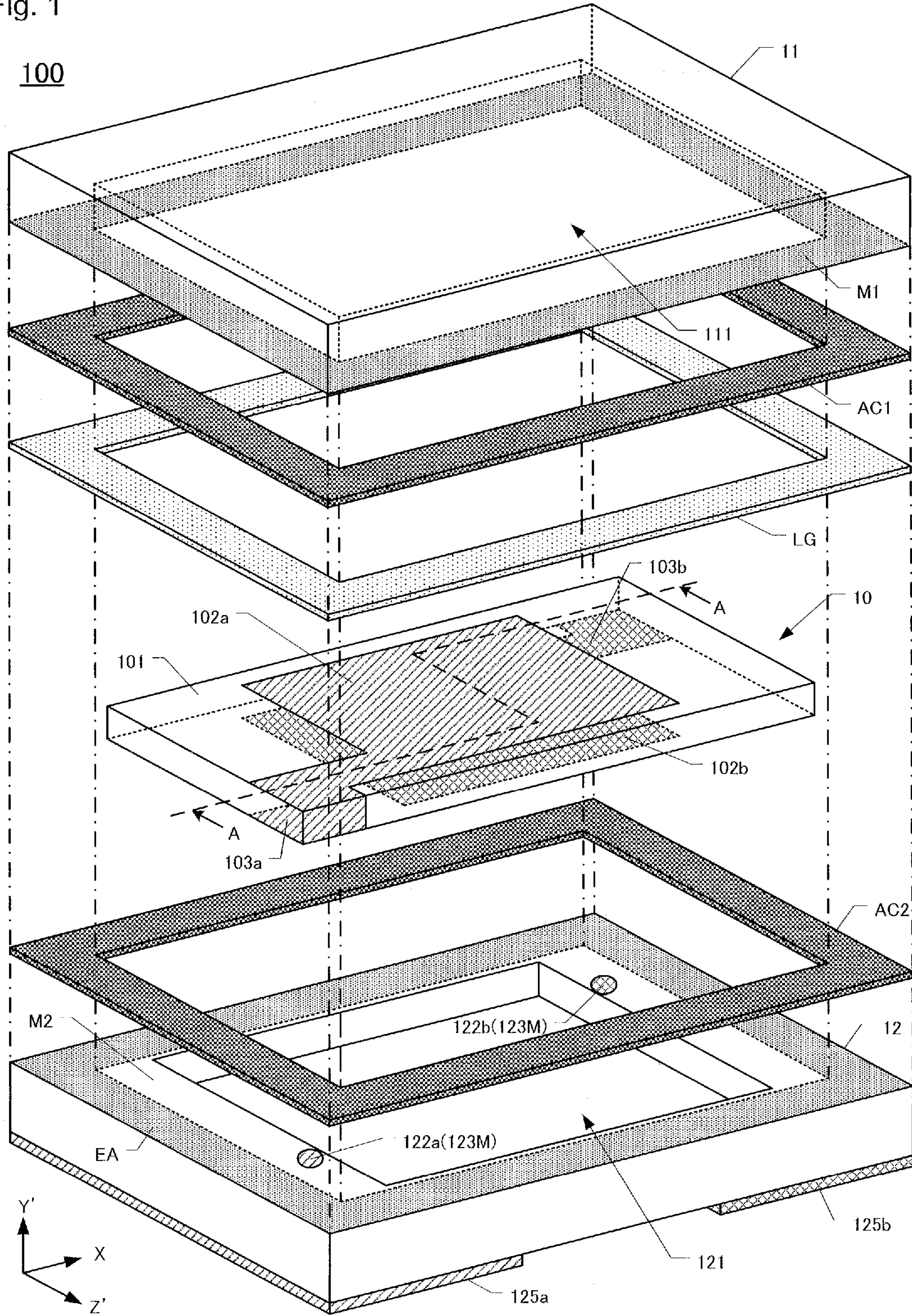


Fig. 2

100

11, 12, 10, CT, 101, 102a, 102b, 103a, 103b, 13, 123M, 122a, 122b, 123a, 123b, 124, 125a, 125b, M1, M2, LG, EA, AC1, AC2, X, Y', Z'

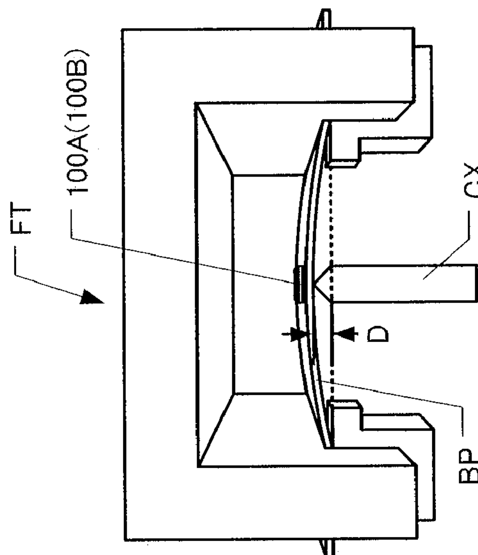


Fig. 3B

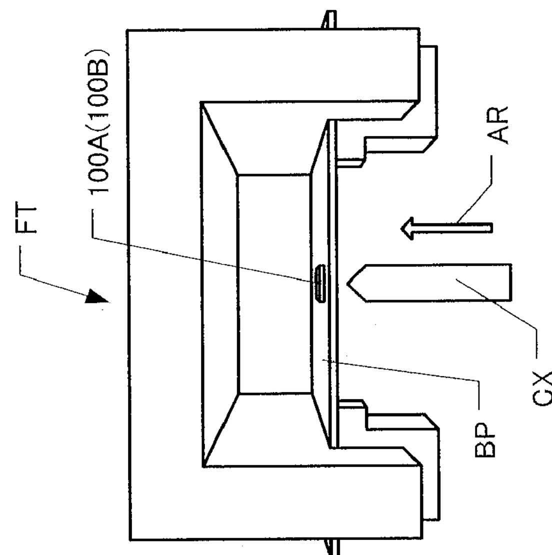


Fig. 3A

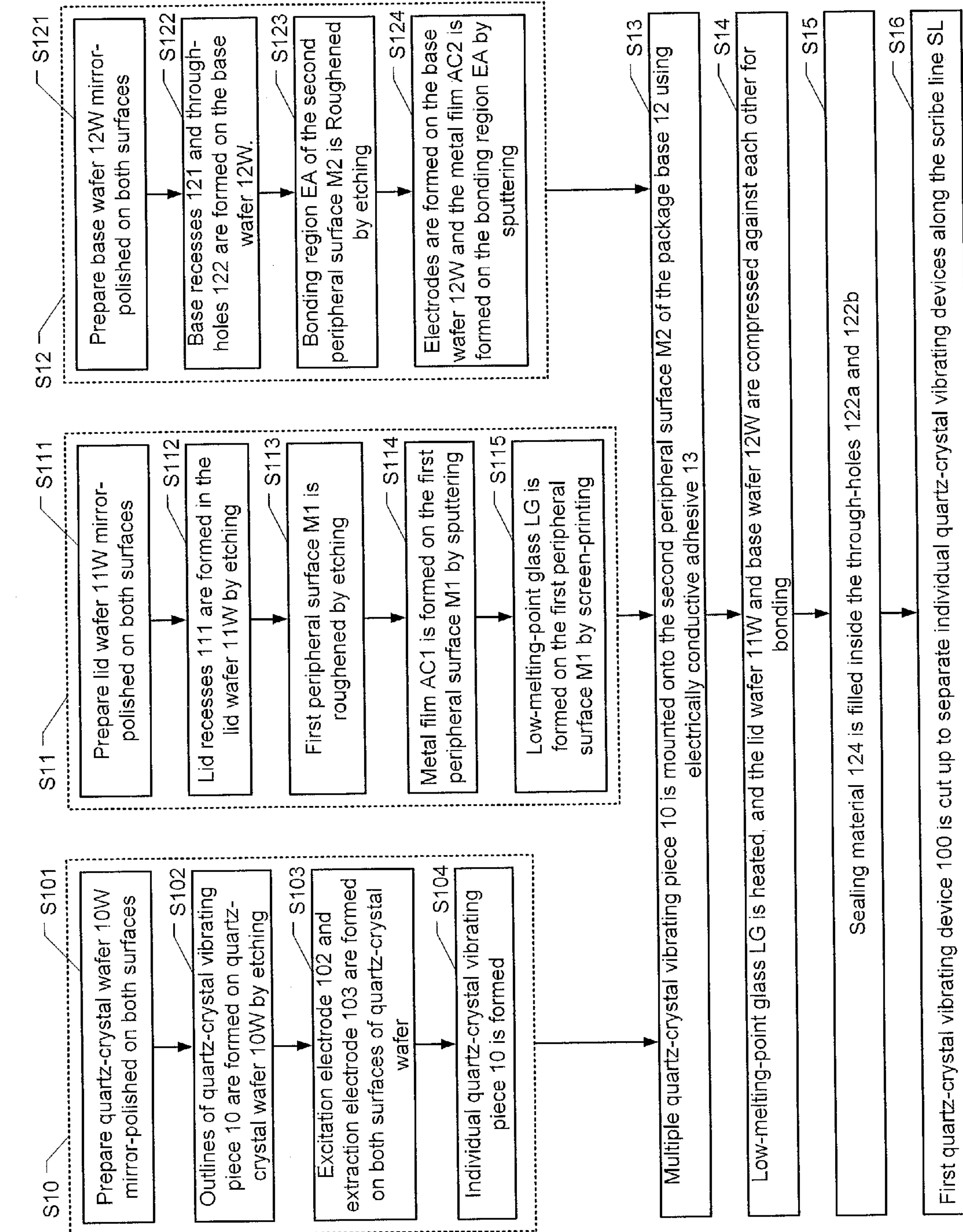


Fig. 4
S10
S101
Prepare quartz-crystal wafer 10W mirror-polished on both surfaces
S102
Outlines of quartz-crystal vibrating piece 10 are formed on quartz-crystal wafer 10W by etching
S103
Excitation electrode 102 and extraction electrode 103 are formed on both surfaces of quartz-crystal wafer
S104
Individual quartz-crystal vibrating piece 10 is formed
S11
S111
Prepare lid wafer 11W mirror-polished on both surfaces
S112
Lid recesses 111 are formed in the lid wafer 11W by etching
S113
First peripheral surface M1 is roughened by etching
S114
Metal film AC1 is formed on the first peripheral surface M1 by sputtering
S115
Low-melting-point glass LG is formed on the first peripheral surface M1 by screen-printing
S12
S121
Prepare base wafer 12W mirror-polished on both surfaces
S122
Base recesses 121 and through-holes 122 are formed on the base wafer 12W.
S123
Bonding region EA of the second peripheral surface M2 is Roughened by etching
S124
Electrodes are formed on the base wafer 12W and the metal film AC2 is formed on the bonding region EA by sputtering
S13
Multiple quartz-crystal vibrating piece 10 is mounted onto the second peripheral surface M2 of the package base 12 using electrically conductive adhesive 13
S14
Low-melting-point glass LG is heated, and the lid wafer 11W and base wafer 12W are compressed against each other for bonding
S15
Sealing material 124 is filled inside the through-holes 122a and 122b
S16
First quartz-crystal vibrating device 100 is cut up to separate individual quartz-crystal vibrating devices along the scribe line SL

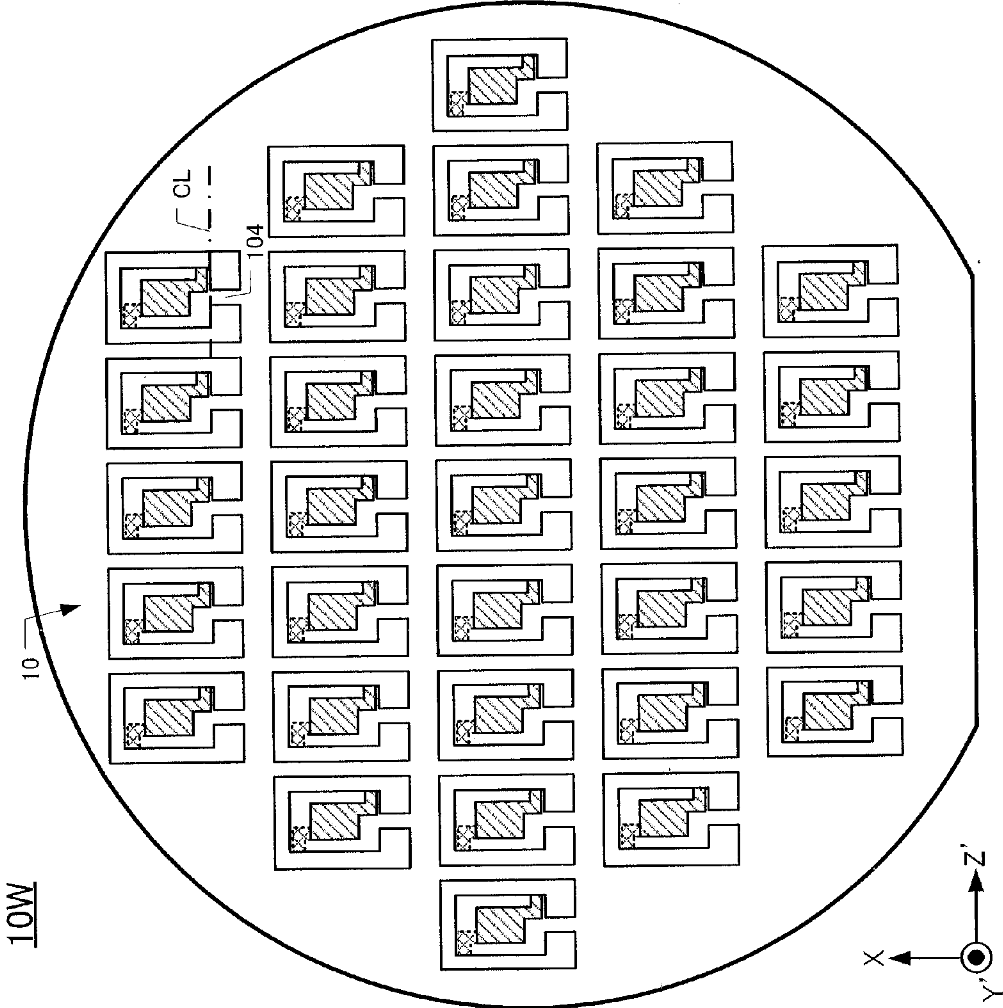
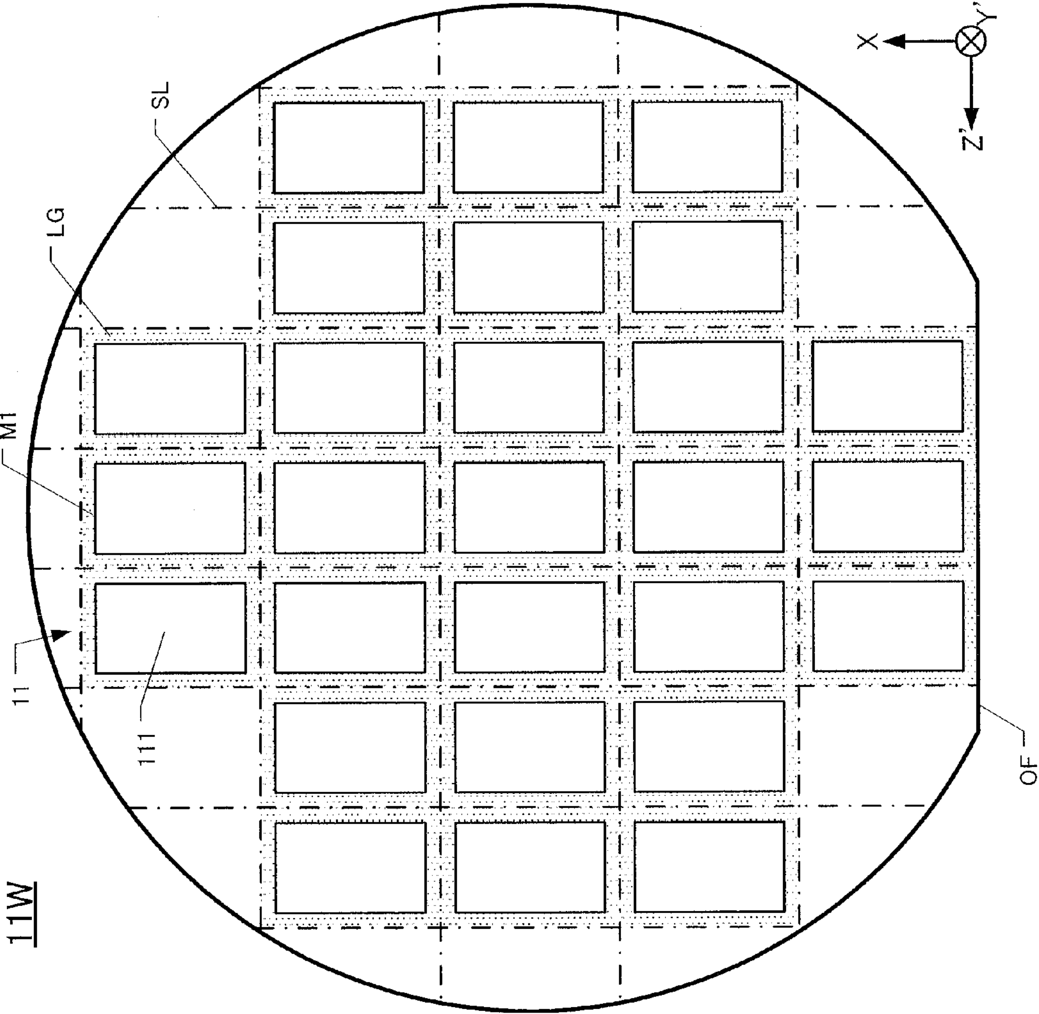


Fig. 5

Fig. 6



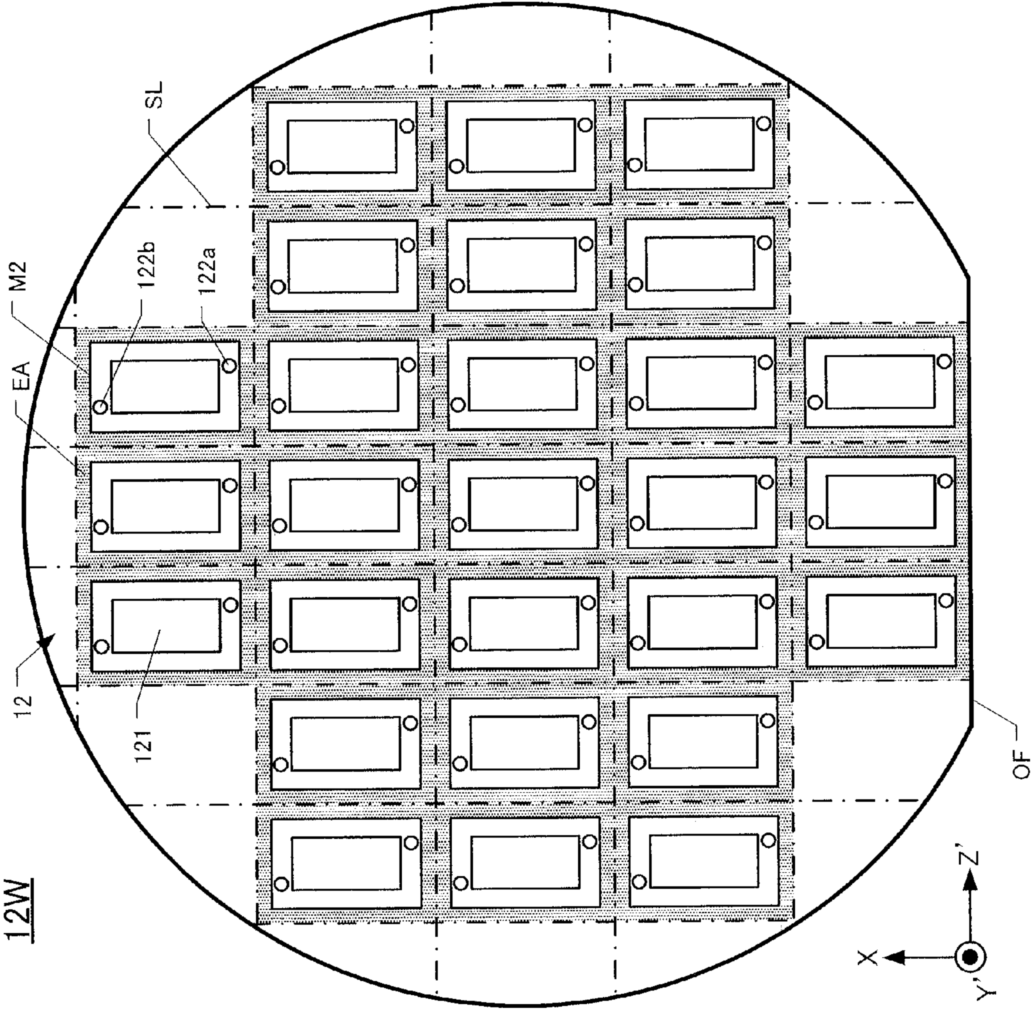


Fig. 7

Fig. 8

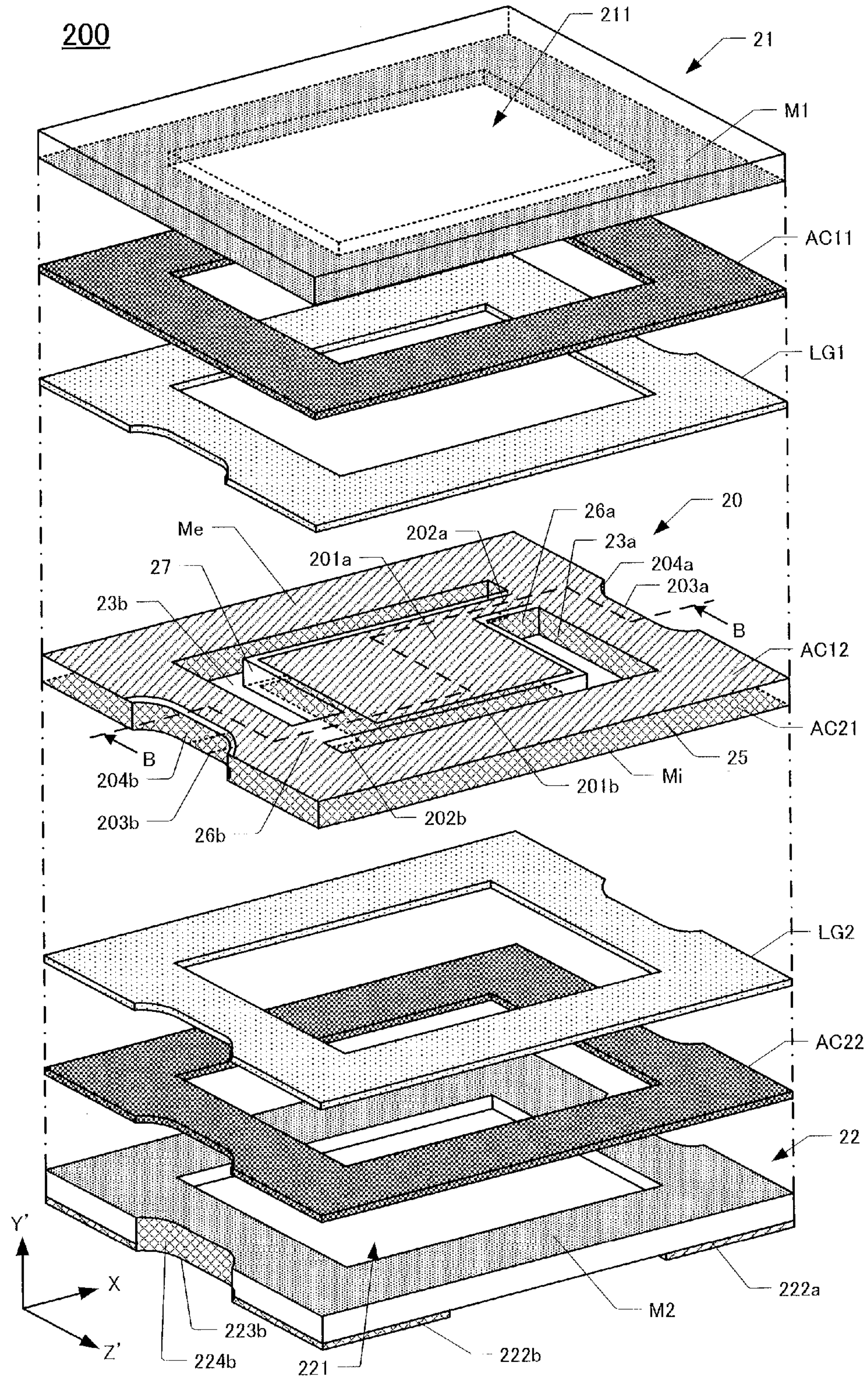


Fig. 9

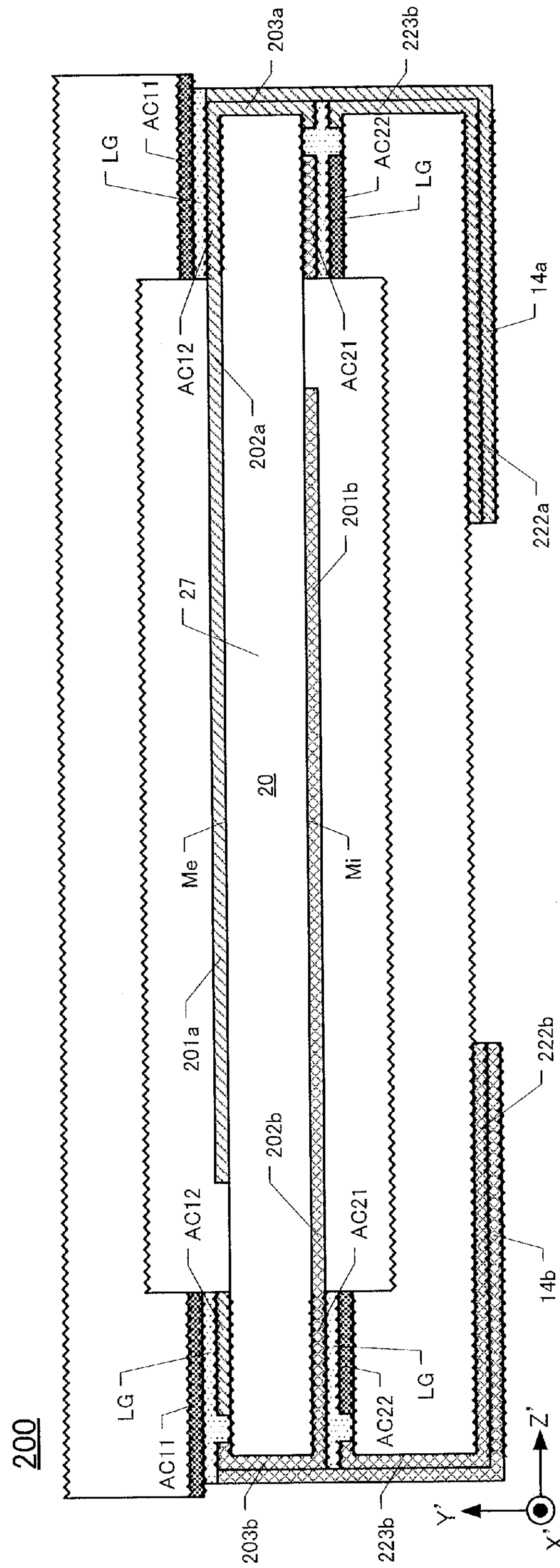


Fig. 10A

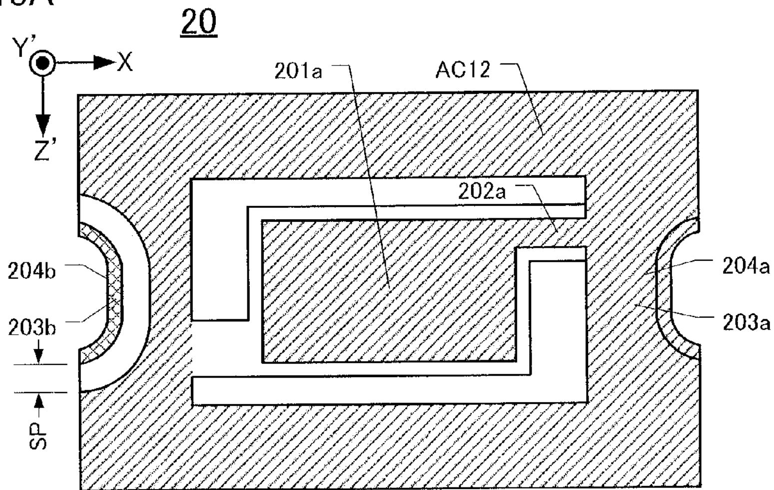


Fig. 10B

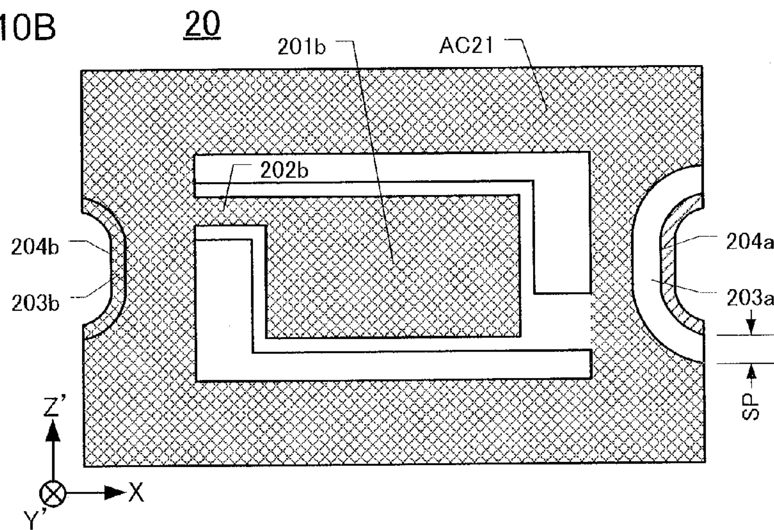
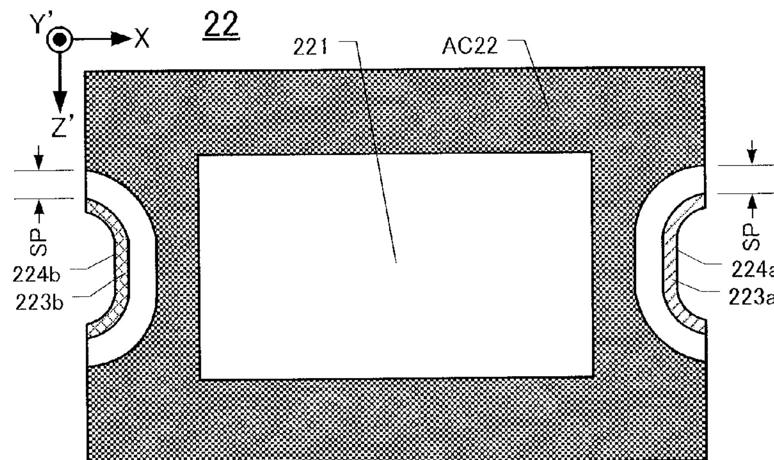


Fig. 10C



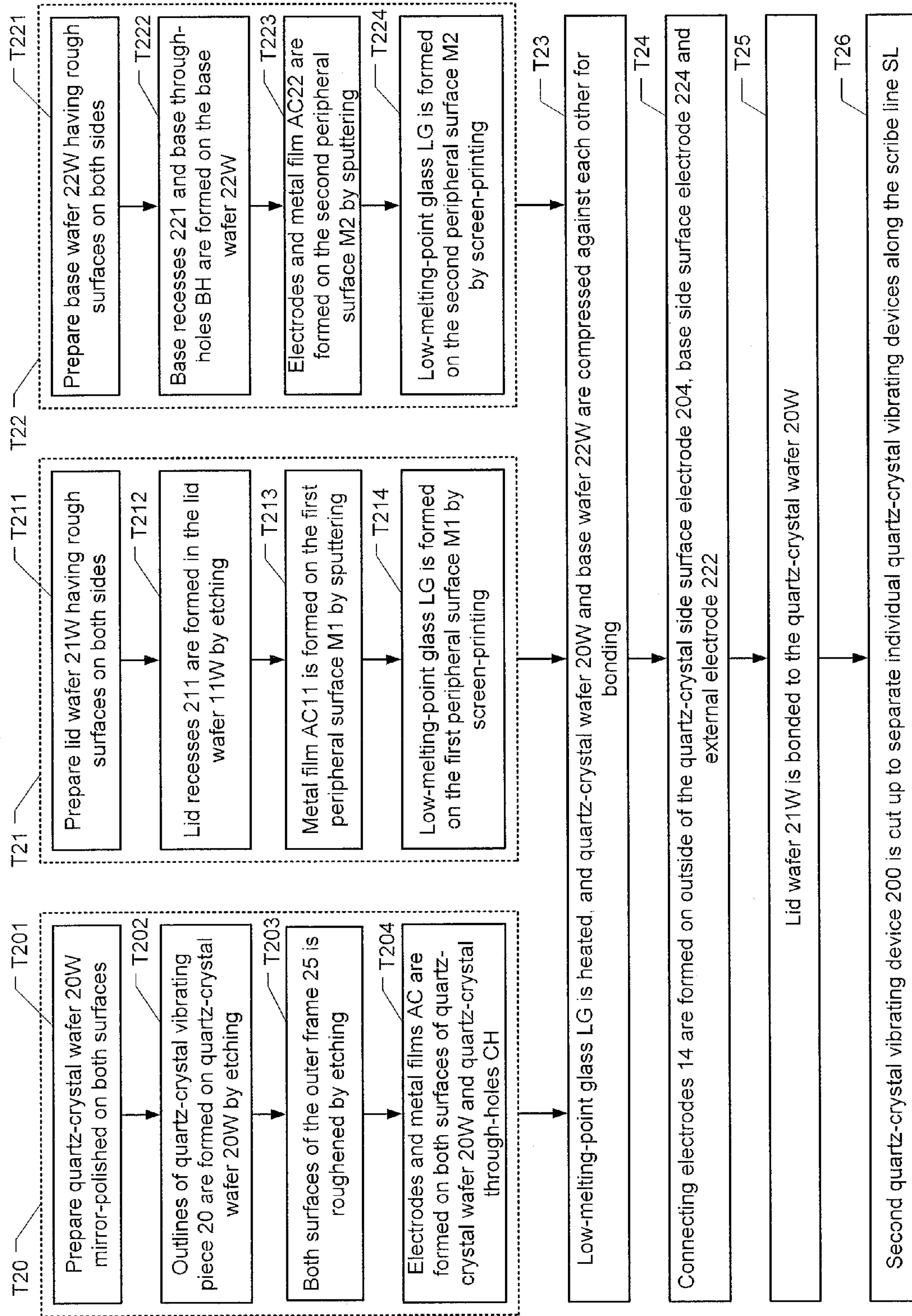


Fig. 11
T20
T201
Prepare quartz-crystal wafer 20W mirror-polished on both surfaces
T202
Outlines of quartz-crystal vibrating piece 20 are formed on quartz-crystal wafer 20W by etching
T203
Both surfaces of the outer frame 25 is roughened by etching
T204
Electrodes and metal films AC are formed on both surfaces of quartz-crystal wafer 20W and quartz-crystal through-holes CH
T21
T211
Prepare lid wafer 21W having rough surfaces on both sides
T212
Lid recesses 211 are formed in the lid wafer 11W by etching
T213
Metal film AC11 is formed on the first peripheral surface M1 by sputtering
T214
Low-melting-point glass LG is formed on the first peripheral surface M1 by screen-printing
T22
T221
Prepare base wafer 22W having rough surfaces on both sides
T222
Base recesses 221 and base through-holes BH are formed on the base wafer 22W
T223
Electrodes and metal film AC22 are formed on the second peripheral surface M2 by sputtering
T224
Low-melting-point glass LG is formed on the second peripheral surface M2 by screen-printing
T23
Low-melting-point glass LG is heated, and quartz-crystal wafer 20W and base wafer 22W are compressed against each other for bonding
T24
Connecting electrodes 14 are formed on outside of the quartz-crystal side surface electrode 204, base side surface electrode 224 and external electrode 222
T25
Lid wafer 21W is bonded to the quartz-crystal wafer 20W
T26
Second quartz-crystal vibrating device 200 is cut up to separate individual quartz-crystal vibrating devices along the scribe line SL

Fig. 12

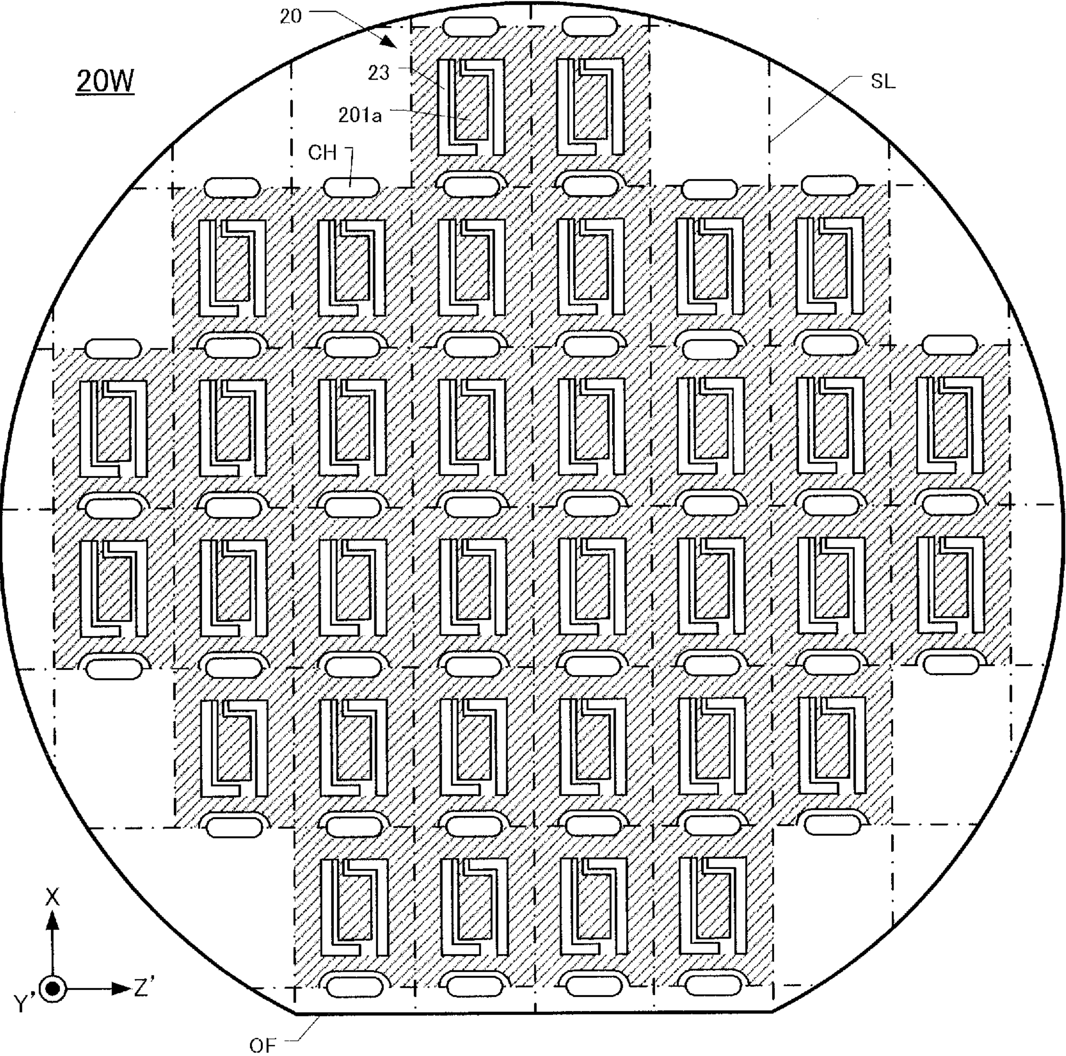


Fig. 13

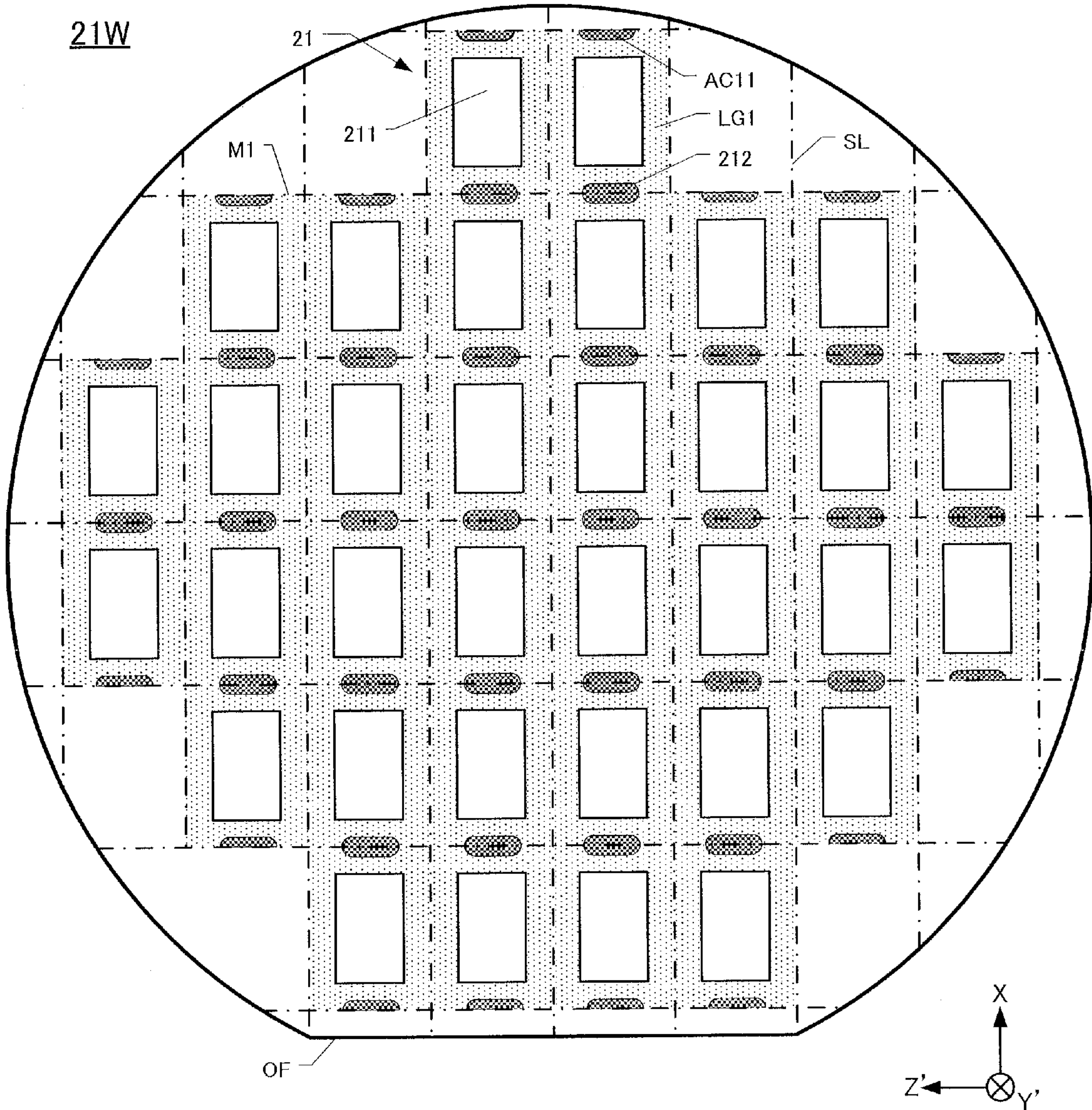
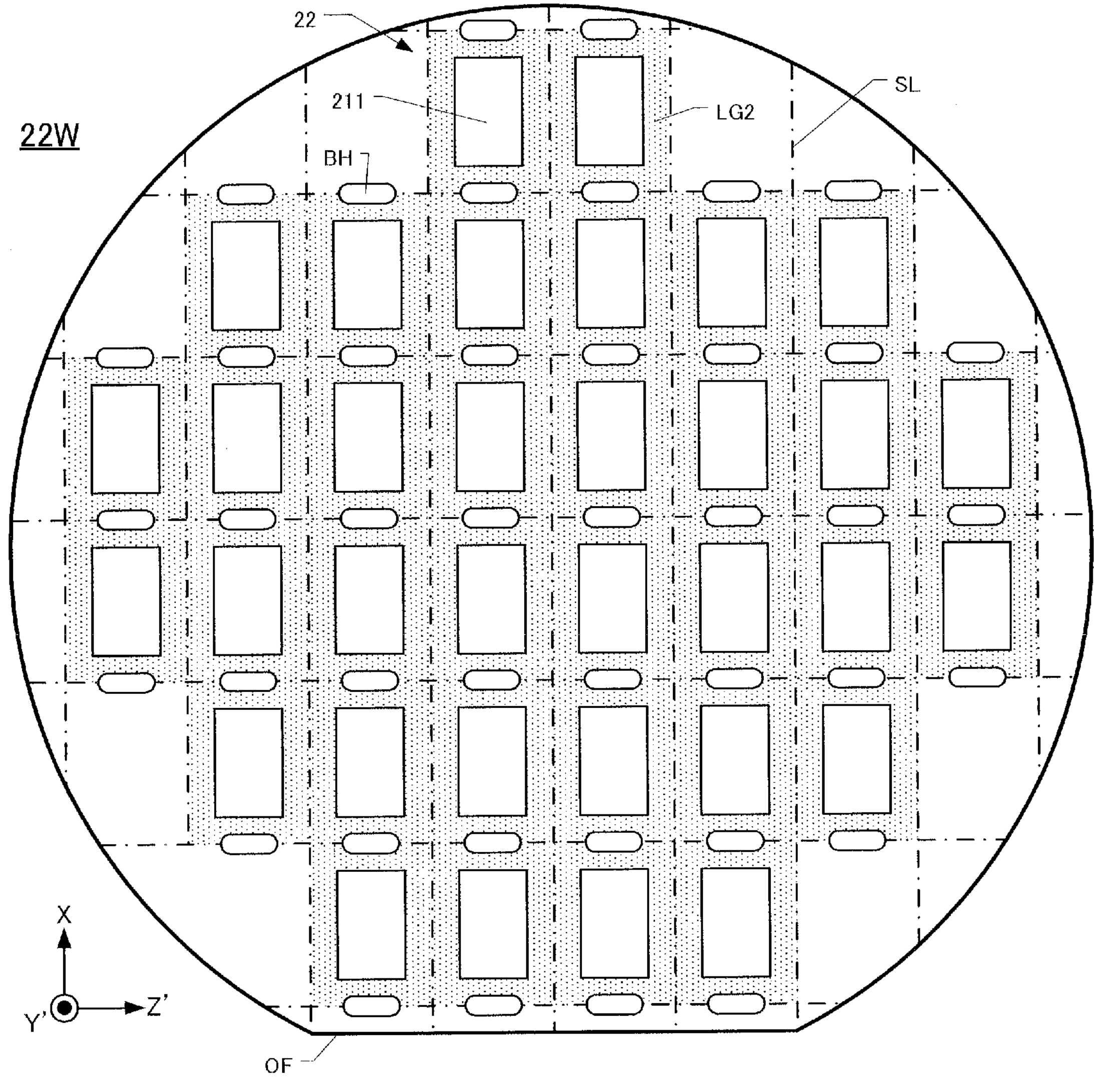


Fig. 14



PIEZOELECTRIC DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to and the benefit of Japan Patent Application No. 2010-217058, filed on Sep. 28, 2010 in the Japan Patent Office, the disclosure of which is incorporated herein by reference in its entirety.

FIELD

[0002] This disclosure pertains to surface-mount type piezoelectric devices having strong adhesion between package bases and package lids.

DESCRIPTION OF THE RELATED ART

[0003] Generally, the surface-mount piezoelectric device comprises a package base for fixing the quartz-crystal vibrating piece and a package lid for covering the quartz-crystal vibrating piece. For example, Japan Unexamined Patent Document No. 2005-175686 discloses a piezoelectric device in which a ceramic base and a glass lid are fixed using a sealing material of, for example, low-melting-point glass. The piezoelectric device disclosed in Japan Unexamined Patent Document No. 2005-175686 may not provide sufficient bonding strength between the base and lid. If the sealing surface of the lid is mirror-polished, the interface between the sealing material and the lid fractures relatively easily. The bond between the sealing material and the sealing surface of the lid is improved if the bonding region (sealing surface) formed on the edge of the lid is made in a rough surface. The rough front surface made of glass is bonded to the ceramic base using the low-melting-point glass, to increase the bonding strength.

[0004] However, as the piezoelectric devices miniaturize, the surface area of the bonding region for applying the sealing material of, for example, low-melting-point glass, decreases in size, and a method for bonding the package lid and the package base with stronger bonding strength became necessary.

[0005] The present invention provides a piezoelectric device having strong bonding strength between the package base and the package lid.

SUMMARY

[0006] A first aspect is directed to a piezoelectric device. In its first aspect, the piezoelectric device stores a piezoelectric vibrating piece which vibrates whenever an electrical voltage is applied. The piezoelectric device comprises: a package lid having a first peripheral surface formed circumferentially on plane in a predetermined width; and; and a package base comprising a second peripheral surface bonded to the first peripheral surface of the package lid and a recess portion recessed from the second peripheral surface. The first peripheral surface of the package lid and the second peripheral surface of the package base are rough surfaces, respective metal films are formed on each rough surface, and the package lid and the package base are bonded using a sealing material formed between the metal films.

[0007] A second aspect is directed to a piezoelectric device. In its second aspect, the piezoelectric vibrating piece is made of a piezoelectric material; and the rough surfaces of the peripheral surfaces are formed rougher than a first surface of the piezoelectric material.

[0008] A third aspect is directed to a piezoelectric device. In its third aspect, the second peripheral surface of the package base is formed wider than the predetermined width; the piezoelectric vibrating piece is mounted onto the second peripheral surface of the package base using an electrically conductive adhesive; and the metal film is formed only on a bonding region of the peripheral surface where the first peripheral surface of the package lid and the second peripheral surface of the package base bond together.

[0009] A fourth aspect is directed to a piezoelectric device. In its fourth aspect, the rough surface is only formed on the bonding region of the second peripheral surface of the package base.

[0010] A sixth aspect is directed to a piezoelectric device. In its sixth aspect, the first peripheral surface of the package lid and the second peripheral surface of the package base have same width; and the piezoelectric vibrating piece is mounted inside and onto the recess defined by the base and/or lid using the electrically conductive adhesive.

[0011] A seventh aspect is directed to a piezoelectric device. In its seventh aspect, a pair of through-holes is formed which extends depthwise through the package base.

[0012] An eighth aspect is directed to a piezoelectric device. In its eighth aspect, a piezoelectric device comprises: a piezoelectric frame having a piezoelectric vibrating piece that vibrates when electrically energized and an outer frame including a first principal surface and a second principal surface formed as to surround the piezoelectric vibrating piece; a package lid having a first peripheral surface that is bonded to the first principal surface of the outer frame of the piezoelectric frame; and a package base having a second peripheral surface that is bonded to the second principal surface of the outer frame of the piezoelectric frame. The first principal surface and the second principal surface of the outer frame, the first peripheral surface of the package lid and the second peripheral surface of the package base have rough surfaces; respective metal films are formed on each rough surface; and the package lid and the outer frame, and the outer frame and the package base are bonded using a sealing material formed between the metal films.

[0013] A ninth aspect is directed to a piezoelectric device. In its ninth aspect, a pair of first castellations is formed on the peripheral edge of the outer frame of the piezoelectric frame, and a pair of second castellations is formed on the peripheral edge of the package base in a position corresponding to the respective first castellations when the piezoelectric frame and the package base are bonded together. The piezoelectric frame comprises: a pair of excitation electrodes formed on the first principal surface and the second principal surface of the piezoelectric vibrating piece; a first extraction electrode on the first principal surface extending from the excitation electrode on the first principal surface to the first castellation; a second extraction electrode on the second principal surface extending from the excitation electrode on the second principal surface to the first castellation; and a first side surface electrode that is electrically connected to the first extraction electrode and formed on the first castellation. The package base comprises a pair of second side surface electrodes that is electrically connected to the first side surface electrode or the second extraction electrode and formed on the pair of second castellations. The pair of connecting electrodes is formed on the first castellations and the second castellations, which electrically connects the first side surface electrode or the first extraction electrode to the second side surface electrode.

[0014] A tenth aspect is directed to a piezoelectric device. In its tenth aspect, the sealing material includes a glass that melts at temperature between 350° C. and 410° C. or a polyimide resin.

[0015] An eleventh aspect is directed to a piezoelectric device. In its eleventh aspect, the package lid and the package base is made of a glass or a piezoelectric material.

[0016] A twelfth aspect is directed to a method for manufacturing a piezoelectric device. In its twelfth aspect, a method for manufacturing a piezoelectric device comprises the steps of: a first preparation step of preparing a piezoelectric vibrating piece that vibrates when electrically energized; a second preparation step of preparing a lid wafer, including a plurality of package lids each having a first peripheral surface formed circumferentially on plane in a predetermined width; a first metal film forming step for forming a metal film on a rough surface on the lid wafer; a third preparation step of preparing a base wafer, including a plurality of package bases each having a second peripheral surface and a recess portion recessed from the second peripheral surface; a second metal film forming step for forming a metal film on a rough surface on the base wafer; a mounting step for mounting the piezoelectric vibrating piece onto the package base using an electrically conductive adhesive; and a bonding step for bonding the lid wafer and the base wafer using a sealing material between the respective metal films on said first and second peripheral surfaces.

[0017] A thirteenth aspect is directed to a method for manufacturing a piezoelectric device. In its thirteenth aspect, the respective rough surfaces on the lid wafer and the base wafer are formed by sand-blasting or etching.

[0018] According to present disclosure, a piezoelectric device having strong bonding strength between the package lid and the package base is provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. **1** is an exploded perspective view of the first quartz-crystal vibrating device **100**.

[0020] FIG. **2** is a cross-sectional view of FIG. **1** taken along A-A line.

[0021] FIG. **3**A is a perspective view of the quartz-crystal vibrating device before performing the experiment to determine the bonding strength.

[0022] FIG. **3**B is a perspective view of the quartz-crystal vibrating device after performing the experiment to determine the bonding strength.

[0023] FIG. **4** is a flow-chart showing the manufacturing method of the first quartz-crystal vibrating device **100**.

[0024] FIG. **5** is a plan view of the quartz-crystal wafer **10**W.

[0025] FIG. **6** is a plan view of the quartz-crystal wafer **11**W.

[0026] FIG. **7** is a plan view of the base wafer **12**W.

[0027] FIG. **8** is an exploded perspective view of the second quartz-crystal vibrating device **200**. Connecting electrodes **14***a* and **14***b* are omitted from the drawing.

[0028] FIG. **9** is a cross-sectional view of FIG. **8** taken along B-B line.

[0029] FIG. **10**A is a plan view of the first surface Me of the quartz-crystal frame **20**, viewed from the +Y'-axis side.

[0030] FIG. **10**B is a plan view of the second surface Mi of the quartz-crystal frame **20**, viewed from the −Y'-axis side.

[0031] FIG. **10**C is a plan view of the package base **22** viewed from the +Y'-axis side.

[0032] FIG. **11** is a flow-chart showing the manufacturing step of the second quartz-crystal vibrating device **200**.

[0033] FIG. **12** is a plan view of the quartz-crystal wafer **20**W.

[0034] FIG. **13** is a plan view of the lid wafer **21**W.

[0035] FIG. **14** is a plan view of the base wafer **22**W.

DETAILED DESCRIPTION

[0036] Various embodiments are described in detail below, with reference to the accompanying drawings. In the described embodiments, an AT-cut quartz-crystal vibrating piece is used as an exemplary piezoelectric vibrating piece. An AT-cut quartz-crystal vibrating piece has a principal surface (in the YZ plane) that is tilted by 35° 15' about the Y-axis of the crystal coordinate system (XYZ) in the direction of the Y-axis from the Z-axis around the X-axis. Thus, in the following description, new axes tilted with respect to the axial directions of the quartz-crystal vibrating piece are denoted as the Y'-axis and Z'-axis, respectively. Therefore, the longitudinal direction of the quartz-crystal vibrating device is referred as the X-axis direction, the height direction is referred as the Y'-axis direction, and the direction normal to the X-axis and Y'-axis directions is referred as the Z'-axis direction, respectively.

First Embodiment

<Overall Configuration of the First Quartz-Crystal Vibrating Device **100**>

[0037] The general configuration of a first quartz-crystal vibrating device **100** is described below with reference to FIGS. **1** and **2**. FIG. **1** is an exploded perspective view of the first quartz-crystal vibrating device **100** and FIG. **2** is a cross-sectional view taken along A-A line of FIG. **1**.

[0038] As shown in FIGS. **1** and **2**, the first quartz-crystal vibrating device **100** comprises a rectangular package lid **11** defining a lid recess **111** configured as a concavity in the inner main surface of the package lid **11**, a package base **12** defining a base recess **121** in the inner main surface of the package base **12**, and a rectangular quartz-crystal vibrating piece **10** mounted on the package base **12**.

[0039] The quartz-crystal vibrating piece **10** comprises an AT-cut quartz-crystal piece **101**. A pair of excitation electrodes **102***a* and **102***b* is disposed substantially centrally on each of the first and second principal surfaces of the quartz-crystal piece **101**, facing each other across the thickness dimension of the quartz-crystal piece **101**. An excitation electrode **102***a* is connected to the extraction electrode **103***a* and extends toward the +Z'-axis corner of bottom surface of the quartz-crystal piece **101** on the −X'-axis side. Similarly, a respective excitation electrode **102***b* is connected to the extraction electrode **103***b* and extends toward the −Z'-axis corner of bottom surface of the quartz-crystal piece **101** on the +X'-axis side. The quartz-crystal vibrating piece **10** is bonded to the package base **12** using electrically conductive adhesive **13**, which is explained hereafter.

[0040] The first quartz-crystal vibrating device **100** comprises a package lid **11**, which is fabricated from a quartz-crystal material or glass, having a lid recess **111** and a first peripheral surface **M1** surrounding the lid recess **111**. The first peripheral surface **M1** is a rough surface having surface roughness Ra of 10 μm to 40 μm. Also, on the first peripheral surface **M1**, a metal film AC**1** is formed, having a foundation layer of chromium (Cr) and overlaying gold (Au) layer. For

the metal film AC1, an exemplary thickness of the chromium layer is approximately 500 Å, and an exemplary thickness of the gold layer is in the range of 1,500 Å to 2,500 Å. Here, since the first peripheral surface M1 for forming the metal film AC1 is rough surface, the metal film AC1 has strong bonding strength to the peripheral surface M1.

[0041] The first quartz-crystal vibrating device **100** further comprises a package base **12**, which is fabricated from a quartz-crystal material or glass, having a base recess **121** and a second peripheral surface M2 surrounding the base recess **121**. The cavity CT for storing the quartz-crystal vibrating piece **10** is defined in part as a concavity in the inner main surface of the lid recess **111** of the package lid **11** and in part by the base recess **121** of the package base **12**. The cavity CT is filled with an inert-gas or is under a vacuum.

[0042] The second peripheral surface M2 has larger width than the first peripheral surface M1. The second peripheral surface M2 comprises a bonding region EA for bonding to the first peripheral surface M1 of the package lid **11**. The bonding region EA is a rough surface having roughness Ra of 10 μm to 40 μm.

[0043] Also, on a bonding region EA on the second peripheral surface M2, a metal film AC2 is formed, having a foundation layer of chromium (Cr) and overlaying gold (Au) layer. For the metal film AC2, an exemplary thickness of the chromium layer is approximately 500 Å, and an exemplary thickness of the gold layer is in the range of 1,500 Å to 2,500 Å. Here, since the bonding region EA on the second peripheral surface M2 for forming the metal film AC2 is rough surface, the metal film AC2 has strong bonding strength to the bonding region EA of the second peripheral surface M2.

[0044] A through-hole **122*a*** is formed with respect to −X-axis side and +Z'-axis direction, so as not to overlap the bonding region EA on the second peripheral surface M2. The through-hole **122*a*** extends through the package base **12**. Similarly, a through-hole **122*b*** is formed with respect to +X-axis side and −Z'-axis direction, which extends through the package base **12**. A pair of through-hole electrodes **123*a*** and **123*b*** are formed on the through-holes **122*a*** and **122*b***, which includes a connecting pad **123**M extending from the mounting surface (mounting surface of a quartz-crystal vibrating device) to the second peripheral surface M2. Further, a pair of external electrodes **125*a*** and **125*b*** are formed on the mounting surface of the package base **12** at both ends in the X-axis direction, each of which external electrodes **125*a***, **125*b*** is electrically connected to respective through-hole electrodes **123*a*** and **123*b***.

[0045] As shown in FIG. **2**, the through-holes **122*a*** and **122*b*** are conically-shaped, spreading toward −Y'-axis side. The shapes are arranged so that, after bonding the package lid **11** and the package base **12**, the through-holes can be easily filled with a sphere-shaped portion of eutectic alloy **124**. As a eutectic alloy **124**, a gold tin (Au—Sn) alloy, gold germanium (Au—Ge) or gold silicon (Au—Si) alloy, or a gold paste or silver paste is used.

[0046] On the quartz-crystal vibrating piece **10** in FIG. **2**, an extraction electrode **103*a*** is electrically connected to the through-hole electrode **123*a*** and an extraction electrode **103*b*** is electrically connected to the through-hole electrode **123*b*** (**123**M), to the second peripheral surface M2 of the package base **12** using the electrically conductive adhesive **13**.

[0047] Thus, the excitation electrodes **102*a*** and **102*b*** on the quartz-crystal vibrating piece **10** are electrically connected to the respective external electrodes **125*a*** and **125*b*** via the respective extraction electrodes **103*a*** and **103*b***, the electrically conductive adhesive **13** and the respective through-hole electrodes **123*a*** and **123*b***. Whenever an alternating voltage (voltage that alternates between positive and negative values) is applied across the pair of external electrodes **125*a*** and **125*b***, the external electrode **125*a***, through-hole electrode **123*a***, extraction electrode **103*a*** and excitation electrode **102*a*** form a same polarity. Similarly, the external electrode **125*b***, through-hole electrode **123*b***, extraction electrode **103*b*** and excitation electrode **102*b*** form a same polarity.

[0048] The package lid **11** and the package base **12** are bonded using low-melting-point glass LG, which is a sealing material for sealing the metal films AC1 and AC2. Low-melting-point glass LG is a lead-free vanadium-based glass having an adhesive component that melts at 350° C. to 410° C. Vanadium-based glass can be formulated as a paste mixed with binder and solvent. Vanadium-based glass bonds to various materials by melting and solidification. The melting point of a vanadium-based glass is lower than the melting point of the package lid **11** or the melting point of the package base **12**, and low-melting-point glass forms a highly reliable air-tight seal and resists water and humidity. Vanadium-based glass resists incursion of atmospheric water vapor into the cavity CT and thus prevents moisture-caused damage to the airtightness of the cavity CT. Also, since the coefficient of thermal expansion of low-melting-point glass can be controlled effectively by controlling its glass structure, the low-melting-point glass can be adjusted to various coefficients of thermal expansion.

[0049] In the first quartz-crystal vibrating device **100**, adhesion strength between the respective surfaces can be strengthened by forming the metal film AC1 on the rough surface of the package lid **11**, and forming the metal film AC2 on the rough surface of the package base **12**. Therefore, even if one of the package lid **11** or the package lid **12** is fabricated from a glass and the other is fabricated from a quartz-crystal material and thus forms difference in the thermal coefficient, the package lid **11** and package base **12** are ensured to be bonded. Also, the presence of gold (Au) layer in the metal film AC1 and AC2, which has large thermal coefficient and is relatively soft, absorbs the difference in the thermal coefficients between components, and prevents the first quartz-crystal vibrating device **100** from being damaged even if used in environments with large temperature changes. Further, such formation minimizes the leakage of gas from outside of the first quartz-crystal vibrating device **100** into the cavity CT or vice versa.

<Bonding Strength of the Quartz-Crystal Vibrating Device>

[0050] In experiments regarding the bonding strength between components of the quartz-crystal vibrating device, it is difficult to determine the stress level at which the package lid and package base separate from each other. Thus, a measurement is taken to determine the amount of bending that can be tolerated the quartz-crystal vibrating device bonded onto a substrate, before the package lid and package base are separated from each other. Therefore, the quartz-crystal vibrating device bonded onto the substrate was bent and the measurement was taken to determine the bending amount of the substrate whenever the package lid and package base were separated from each other.

[0051] FIG. **3**A is a perspective view of the quartz-crystal vibrating device. In this drawing, FIG. **3**A is a perspective view before performing the experiment to determine the

bonding strength, and FIG. **3**B is a perspective view after performing the experiment to determine the bonding strength.

[0052] As shown in FIG. **3**A, both edges of the substrate BP of the first quartz-crystal vibrating device **100**A or **100**B bonded using solder is sandwiched and fixed to a fixture FT. Then, a portion of the substrate BP bonded to the quartz-crystal vibrating device **100**A or **100**B is pressed using the pressing material CX, as indicated with arrow AR in the figure.

[0053] Thus, as shown in FIG. **3**B, the substrate BP is bent in an arch form. The amount pressed using pressing material CX for deforming the substrate BP is referred as bending amount D. The bending amount D refers to the distance between the position of the quartz-crystal vibrating device **100**A or **100**B before pressing to the position after pressing.

[0054] Thus, the experiment for determining the bending strength of the quartz-crystal vibrating device determines the strength where the package lid and package base of the quartz-crystal vibrating device **100**A or **100**B separate. The result is as shown in the chart 1 below.

No.	Types	Metal Films Lid	Metal Films Base	Average Bending Amount D (mm) of the Substrate BP (when peeled off)
1	Quartz-crystal Vibrating Device 100A	No	No	6.67
2	Quartz-crystal Vibrating Device 100B	Yes	Yes	7.86

[0055] As shown in chart 1, the metal films are not formed on the bonding surface of the package lid or package base of the quartz-crystal vibrating device **100**A. On the other hand, the metal films are formed on the bonding surface of the package lid and package base of the quartz-crystal vibrating device **100**B. In the experiment for determining the bending strength of the quartz-crystal vibrating device, the package lid and the package base of the quartz-crystal vibrating device **100**A and **100**B are bonded using the same type of the low-melting-point glass at the same temperature (400° C.). Here, the bending amount D of the substrate BP at the time of being peeled off refers to the distance of the substrate BP bent whenever the package lid and package base were peeled off (separated). The average value of the bending amount D of the substrate BP at the time of peeled off refers to the average of five bending amounts D after performing experiments for five times, for example.

[0056] As understood from the chart 1, the average of the bending amount (7.86 mm) of the substrate BP of the quartz-crystal vibrating device **100**B with a metal film formed, is larger than the average of the bending amount (6.67 mm) of the substrate BP of the quartz-crystal vibrating device **100**A without a metal film. In other words, whenever a metal film is formed between the package lid and the package base, the bonding strength between the package lid and package base increases, thus reducing the risk of the package lid and the package base of the quartz-crystal vibrating device separating from each other.

<Leakage of the Quartz-Crystal Vibrating Device>

[0057] Experiments were performed in order to determine the leakage of vapors from outside into the cavity CT or vice versa, using the quartz-crystal vibrating device **100**A without metal film and the quartz-crystal vibrating device **100**B with metal film. Chart 2 shows the experiment result of the leakage of quartz-crystal vibrating devices by using seven pieces for each quartz-crystal vibrating devices **100**A and **100**B. “Leak OK” in the chart refers to the condition without any leakage found. The condition without any leakage found is a leak rate of 1.1×10^{-9} Pa·m^3/s or lower.

No.	Types	Metal Films Lid	Metal Films Base	No. of Samples	Leak OK	Leak Defect Rate (%)
1	Quartz-crystal Vibrating Device 100A	No	No	7	5	28.6%
2	Quartz-crystal Vibrating Device 100B	Yes	Yes	7	7	0.0%

[0058] As shown in chart 2, out of seven quartz-crystal vibrating devices **100**A without metal film, five quartz-crystal vibrating devices **100**A passes the leakage experiment, which is indicated as “leak OK” in the chart. Thus, the leak defect rate is 28.6%. On contrary, all seven quartz-crystal vibrating devices **100**B with metal film passes the leakage experiment, which is indicated as “leak OK” in the chart. Thus, the leak defect rate is 0%.

[0059] As shown in charts 1 and 2, the package lid and the package base on the quartz-crystal vibrating device **100**B are less likely to be peeled off (separated) from each other, and the quartz-crystal vibrating device **100**B has less vapor leakage from outside into the cavity CT or vice versa, in comparison to the quartz-crystal vibrating device **100**A.

[0060] In the first quartz-crystal vibrating device **100** in the first embodiment, although the rough surface is formed only on the bonding region EA of the second peripheral surface M**2**, it can be applied to the quartz-crystal vibrating device having rough surface on entire second peripheral surface M**2**. Also, although the metal films are formed on both package lid **11** and package base **12** in the first embodiment, the metal film can be situated only on one of the respective surfaces M**1**, M**2**.

[0061] Further, in the first quartz-crystal vibrating device **100**, the second peripheral surface M**2** on the package base **12** is formed wider than the first peripheral surface M**1** on the package lid **11**, so as to leave room to dispose the piezoelectric vibrating piece **10** on the second peripheral surface M**2** of the package base **12**. However, it can be applied to the quartz-crystal vibrating device having the same width of the first peripheral surface M**1** and second peripheral surface M**2**, with the piezoelectric vibrating piece **10** mounted inside the base recess **121** of the package base. Also, whenever the piezoelectric vibrating piece **10** is mounted onto the base recess **121** of the package base **12**, the package lid can be a planar plate without a recess.

[0062] Furthermore, on the first quartz-crystal vibrating device **100**, a groove can be formed on the second peripheral surface M**2** of the package base **12**, so as to prevent the overflowing low-melting-point glass LG from entering between the bonding region EA and electrically conductive adhesive **13**.

<Manufacturing Method of the First Quartz-Crystal Vibrating Device **100**>

[0063] FIG. **4** is a flow-chart of an embodiment of a method for manufacturing the first embodiment of a first quartz-crystal vibrating device **100**. In FIG. **4**, the protocol S**10** for manufacturing the quartz-crystal vibrating piece **10**, the protocol S**11** for manufacturing the package lid **11**, and the protocol S**12** for manufacturing the package base **12** can be carried out separately or in parallel. FIG. **5** is a plan view of the quartz-crystal wafer **10**W, FIG. **6** is a plan view of the lid wafer **11**W, and FIG. **7** is a plan view of the base wafer **12**W.

[0064] In protocol S**10**, the quartz-crystal vibrating piece **10** is manufactured. The protocol S**10** includes steps S**101** to S**104**.

[0065] In step S**101**, a quartz-crystal wafer **10**W, mirror-polished on both sides, is prepared. A half-finished quartz-crystal wafer (not drawn), obtained by an AT-cut from a raw quartz-crystal, have, a rough surface, convexities and concavities on entire surface. If a half-finished quartz-crystal wafer is used as it is, a rough surface with convexities and concavities causes diffused reflection during the photoresist using the exposing tool, thus making the formation of outlining difficult. Therefore, the quartz-crystal wafer **10**W is manufactured by mirror-polishing both surfaces of the half-finished AT-cut quartz-crystal wafer obtained by polishing the raw quartz-crystal material.

[0066] In step S**102**, as shown in FIG. **5**, outlines of the plurality of quartz-crystal vibrating piece **10** are formed on a planer quartz-crystal wafer **10**W by etching. Here, each quartz-crystal vibrating piece **10** is connected to the quartz-crystal wafer **10**W by a joining portion **104**.

[0067] In step S**103**, a foundation layer of chromium and overlaying gold layer is applied onto both surfaces and side surfaces of the quartz-crystal wafer **10**W by sputtering or vacuum-deposition. Then, a photoresist is uniformly applied onto entire surface of the metal layer. Using an exposure tool (not shown), outline patterns of the excitation electrodes **102***a* and **102***b*, and extraction electrodes **103***a* and **103***b* drawn on the photomask are exposed on the quartz-crystal wafer **10**W. Next, the metal layer exposed from photoresist is etched. Thus, as shown in FIG. **5**, excitation electrodes **102***a* and **102***b*, and extraction electrodes **103***a* and **103***b* are formed on both surfaces and side surfaces of the quartz-crystal wafer **10**W (refer to FIG. **1**).

[0068] In step S**104**, individual quartz-crystal vibrating pieces **10** are cut into separate pieces. During cutting, quartz-crystal vibrating pieces **10** are cut along cut lines CL (denoted by dot-dash lines in FIG. **6**) using a dicing unit such as a laser beam or dicing saw.

[0069] In protocol S**11**, the package lid **11** is manufactured. Protocol S**11** includes steps S**111** to S**115**.

[0070] In step S**111**, a lid wafer **11**W, mirror-polished on both surfaces, is prepared. Whenever a quartz-crystal material is used as the lid wafer **11**W, both surfaces of the half-finished lid wafer, obtained from a raw quartz-crystal material by AT-cut or Z-cut, is mirror-polished with an abrasive.

[0071] In step S**112**, as shown in FIG. **6**, several hundreds to several thousands of lid recesses **111** are formed on the lid wafer **11**W, a circular, uniformly planar plate of quartz-crystal material. The lid recesses **111** are formed in the lid wafer **11**W by etching or mechanical processing, leaving the first peripheral surfaces M**1** around the lid recesses **111**.

[0072] In step S**113**, the first peripheral surface M**1** is etched or sand-blasted, roughening first surface by Ra 10 μm to Ra 40 μm (refer to FIG. **2**).

[0073] In step S**114**, the first metal film AC**1** comprising the chromium layer and the gold layer is formed on the first peripheral surface M**1** by sputtering and etching method explained in step S**103**.

[0074] In step S**115**, as shown in FIG. **6**, the low-melting-point glass LG is imprinted on the metal film AC**1** of the first peripheral surface M**1** of the lid wafer **11**W by screen-printing. Then, the low-melting-point glass LG is formed on the first peripheral surface M**1** of the lid wafer **11**W by preliminary curing.

[0075] In protocol S**12**, the package base **12** is manufactured. Protocol S**12** includes steps S**121** to S**124**.

[0076] In step S**121**, the base wafer **12**W, mirror-polished on both surfaces, is prepared. Whenever a quartz-crystal material is used as the base wafer **12**W, both surfaces of the half-finished lid wafer obtained from a raw quartz-crystal material by AT-cut or Z-cut, are mirror-polished using an abrasive.

[0077] In step S**122**, as shown in FIG. **7**, several hundreds to several thousands of lid recesses **111** are formed on the lid wafer **11**W, a circular, uniformly planar plate of quartz-crystal material. The base recesses **121** are formed in the base wafer **12**W by etching or mechanical processing, leaving the second peripheral surfaces M**2** around the base recesses **121**. Also formed are respective through-holes **122***a* and **122***b* on each edge of the package base **12** in respective X-axis directions. The through-holes extend depthwise through the base wafer **12**W.

[0078] In step S**123**, the bonding region EA of the second peripheral surface M**2** is etched or sand-blasted, roughening the surface by Ra 10 μm to Ra 40 μm (refer to FIG. **2**).

[0079] In step S**124**, as shown in FIG. **2**, external electrodes **125***a* and **125***b* are formed on the mounting surface of package base **12** (mounting surface of quartz-crystal vibrating device), and respective through-hole electrodes **123***a* and **123***b* are formed on the through-holes **122***a* and **122***b*, by etching and sputtering (the same method as used in step S**102**). Simultaneously, the metal film AC**2**, comprising the chromium layer and gold layer, is formed on the bonding region EA of the second peripheral surface M**2**.

[0080] In step S**13**, the quartz-crystal vibrating piece **10** (manufactured in protocol S**10**) is mounted onto the second peripheral surface M**2** of the package base **12** using electrically conductive adhesive **13**. The quartz-crystal vibrating piece **10** is mounted onto the second peripheral surface M**2** of the package base **12**, so as to align the extraction electrodes **103***a* and **103***b* on the quartz-crystal vibrating piece **10** with respective connecting pad **123**M formed on the second peripheral surface M**2** of the package base **12** (refer to FIG. **2**).

[0081] In step S**14**, the low-melting-point glass LG is heated, and the lid wafer **11**W and base wafer **12**W are compressed against each other for bonding via the low-melting-point glass LG.

[0082] In step S**15**, the eutectic alloy **124** (refer to FIG. **2**) made of gold tin (Au—Sn) alloy, gold germanium (Au—Ge) or gold silicone (Au—Si) is filled inside the through-holes **122***a* and **122***b*. The eutectic alloy **124** is melted in a vacuum or reflow chamber filled with inert gas, for sealing the wafers.

Thus the multiple first quartz-crystal vibrating devices **100** having a cavity under a vacuum or filled with an inert-gas is prepared.

[0083] In step S**16** the bonded-together lid wafer **11**W and base wafer **12**W is cut up to separate individual quartz-crystal vibrating devices **100** from the wafer and from each other. This cutting is performed by cutting along scribe lines SL, denoted by dot-dash lines in FIGS. **6** and **7**, using a dicing unit such as a laser beam or a dicing saw. Thus, several hundreds to several thousands of quartz-crystal vibrating devices **100** are produced.

Second Embodiment

<Overall Configuration of the Second Quartz-Crystal Vibrating Device **200**>

[0084] The general configuration of a second quartz-crystal vibrating device **200** is described below with reference to FIGS. **8** to **10**.

[0085] FIG. **8** is an exploded perspective view of the second quartz-crystal vibrating device **200**, and the connecting electrodes **14***a* and **14***b* are omitted from the drawing. FIG. **9** is a cross-sectional view of FIG. **8** taken along B-B line of FIG. **8**. FIG. **10**A is a plan view of the first surface Me of the quartz-crystal frame **20** as viewed from the +Y'-axis side, FIG. **10**B is a plan view of the second surface Mi of the quartz-crystal frame **20** as viewed from the −Y'-axis side, and FIG. **10**C is a plan view of the package base **22** as viewed from +Y'-axis side.

[0086] As shown in FIGS. **8** and **9**, the second quartz-crystal vibrating device **200** comprises a rectangular package lid **21** defining a lid recess **211** configured as a concavity in the inner main surface of the package lid **21**, a package base **22** defining a base recess **221** in the inner main surface of the package base **12**, and an AT-cut quartz-crystal frame **20** sandwiched between the package lid **21** and package base **22**. The package lid **21** has same configuration as the package lid **11** explained in the first embodiment.

[0087] The quartz-crystal frame **20** has a first surface Me and a second surface Me opposing the first surface, and comprises a quartz-crystal vibrating portion **27**, having respective excitation electrodes **201***a* and **201***b* on both surfaces, and an outer frame **25** surrounding the quartz-crystal vibrating portion **27**. Between the quartz-crystal vibrating portion **27** and the outer frame **25**, a pair of joining portions **26***a* and **26***b* are formed along the quartz-crystal vibrating portion **27** in both X-axis directions, which connects to the outer frame **25**. Between the quartz-crystal vibrating portion **27** and the outer frame **25**, two "L-shaped" gaps **23***a* and **23***b* are formed. An extraction electrode **202***a* is formed on the first surface Me of the joining portion **26***a*, which extends from the excitation electrode **201***a*, and an extraction electrode **202***b* is formed on the second surface Mi of the joining portion **26***a*, which extends from the excitation electrode **202***b*.

[0088] Respective quartz-crystal castellations **204***a* and **204***b* are formed on both sides extending in the Z'-axis directions of the quartz-crystal frame **20** in respective X-axis directions, which is formed as the rounded-rectangular quartz-crystal through-holes CH (refer to FIG. **12**). Respective quartz-crystal side surface electrodes **203***a* and **203***b* are formed on quartz-crystal castellations **204***a* and **204***b*.

[0089] The first surface Me and the second surface Mi of the outer frame **25** is a rough surface having roughness Ra of 10 μm to 40 μm. On the first surface Me and the second surface Mi, respective metal films AC**12** and AC**21** are formed, which are electrically connected to extraction electrodes **202***a* and **202***b*. Thus the extraction electrode **202***a* is connected to the quartz-crystal side surface electrode **203***a* via the metal film AC**12**, and the extraction electrode **202***b* is connected to the quartz-crystal side surface electrode **203***b* via the metal film AC**21**. The first metal film AC**12** and AC**21** comprises a foundation layer of chromium (Cr) and overlaying gold (Au) layer. An exemplary thickness of the chromium layer is approximately 500 Å, and an exemplary thickness of the gold layer is in the range of 1,500 Å to 2,500 Å. Here, rough surface of the first surface Me and second surface Mi for forming metal films AC**12** and AC**21** allows strong adhesion of metal films AC**12** and AC**21** to the respective surfaces Me and Mi.

[0090] Here, whenever an alternating voltage (voltage that alternates positives and negatives) to the external electrodes **222***a* and **222***b*, the quartz-crystal side surface electrodes **203***a* and **203***b*, and the excitation electrodes **201***a* and **201***b*, form different polarity. Therefore, metal films AC12 and AC21 are formed so as to prevent electrodes having different polarities from electrical short.

[0091] The metal film AC**12** connects the excitation electrode **201***a* and the quartz-crystal side surface electrode **203***a*, and the metal film AC**21** connects the excitation electrode **201***b* and the quartz-crystal side surface electrode **203***b*. As shown in FIG. **10**A, the metal film AC**12** connected to the excitation electrode **201***a* is formed at a predefined distance SP away from the quartz-crystal side surface electrode **203***b*, so as to prevent a short with the quartz-crystal side surface electrode **203***b* connected to the excitation electrode **201***b*. Similarly, as shown in FIG. **10**B, the metal film AC**21** connected to the excitation electrode **201***b* is formed at a predefined distance SP away from the quartz-crystal side surface electrode **203***a*, so as to prevent a short with the quartz-crystal side surface electrode **203***a* connected to the excitation electrode **201***a*.

[0092] Going back to FIGS. **8** and **9**, the second quartz-crystal vibrating device **200** further comprises a package base **22** having a second peripheral surface M**2** surrounding the base recess **221** and fabricated from the quartz-crystal material. The cavity CT is formed for situating the quartz-crystal vibrating portion **27** with the package lid **21** and the outer frame **25** of the quartz-crystal frame **20**. The cavity CT is filled with inert gas or under a vacuum.

[0093] A pair of external electrodes **222***a* and **222***b* is formed on the mounting surface (mounting surface of the quartz-crystal vibrating device) on both sides in respective X-axis directions of the package base **22**. The base castellations **224***a* and **224***b* are formed on both ends of the package base **22** in respective X-axis directions, so as to correspond to the quartz-crystal castellations **204***a* and **204***b* of the quartz-crystal frame **20**. The base castellations **224***a* and **224***b* are formed simultaneously with the rounded-rectangular base through-holes BH (refer to FIG. **14**). On the base castellations **224***a*, a base side surface electrode **223***a* is formed, in which one end is connected to the external electrode **222***a*, and the other end is connected to the quartz-crystal castellations **204***a* of the quartz-crystal frame **20**. Similarly, on the base castellations **224***b*, a base side surface electrode **223***b* is formed, in which one end is connected to the external electrode **222***b*, and the other end is connected to the metal film AC**21** of the quartz-crystal frame **20**.

[0094] Thus, the excitation electrodes **201***a* and **201***b* are connected to the respective external electrodes **222***a* and **222***b* through the extraction electrode **202***a* and **202***b*, metal films AC**12** and AC**21**, quartz-crystal side surface electrode **203***a* and base side surface electrodes **223***a* and **223***b*.

[0095] The second peripheral surface M**2** of the package base **22** is a rough surface having surface roughness Ra of 10 μm to 40 μm. On the second peripheral surface M**2**, a metal film AC**22** is formed, which comprises a foundation layer of chromium (Cr) and overlaying gold (Au). An exemplary thickness of the chromium layer is approximately 500 Å, and an exemplary thickness of the gold layer is in the range of 1,500 Å to 2,500 Å. Here, the rough surface of the second peripheral surface M**2** for forming the metal film AC**22** increases the adhesion of metal film AC**22** to the second peripheral surface M**2**.

[0096] Here, the metal film AC**22** is formed, so as to prevent the package base side surface electrode **223***a* and the base side surface electrode **223***b* from electric short. Specifically, as shown in FIG. **10**C, the metal film AC**22** is formed at a predetermined distance SP away from respective base side surface electrodes **223***a* and **223***b*, so as to prevent electrical short. Although the metal film AC**22** is formed at a predetermined distance SP away from both base side surface electrodes **223***a* and **223***b*, at least one electrode can be connected to the metal film AC**22**.

[0097] Going back to FIGS. **8** and **9**, the package lid **21** and the quartz-crystal frame **20** are bonded using the low-melting-point glass LG, a sealing material for the metal films AC**11** and AC**12**. Similarly, the quartz-crystal frame **20** and the package base **22** are bonded using the low-melting-point glass LG, a sealing material for the metal films AC**21** and AC**22**.

[0098] In the second quartz-crystal vibrating device **200**, the metal film AC**11** is formed on the rough surface of the package lid **11**, the metal films AC**12** and AC**21** are formed on both rough surfaces of the quartz-crystal frame **20**, and the metal film AC**22** is formed on the rough surface of the package base **22**, thus providing stronger bonding strength. Thus the package lid **21**, the quartz-crystal frame **20** and the package base **22** are ensured to be reliably bonded (refer to chart 1). Further, since the package lid **21**, the quartz-crystal frame **20** and the package base **22** are ensured to be bonded, thus creating greater resistance to leakage into or out of the quartz-crystal vibrating device **200** (refer to chart 2).

[0099] As shown in FIG. **9**, the connecting electrodes **14***a* and **14***b* of the second quartz-crystal vibrating device **200** are formed, so as to cover entire or part of the external electrodes **222***a* and **222***b*, the base side surface electrodes **223***a* and **223***b*, and the quartz-crystal side surface electrode **203***a* and **203***b*. Thus, the connecting electrodes **14***a* and **14***b* are ensured to be connected to the quartz-crystal side surface electrode **203***a* and the base side surface electrode **223***a*, in which the low-melting-point glass LG could not connect, as well as the metal film AC**21** and the base side surface electrode **223***b*. Therefore, the external electrodes **222***a* and **222***b* are ensured to be electrically connected to the excitation electrodes **201***a* and **201***b*.

[0100] In the second quartz-crystal vibrating device **200**, although the quartz-crystal castellations and the base castellations are illustrated as rounded-rectangular castellations formed on opposite ends in the X-axis direction of the quartz-crystal frame and the package base, the castellations can take the form of quarter-rounded castellations formed on each corner of the quartz-crystal frame and the package base.

<Manufacturing Method of the Second Quartz-Crystal Vibrating Device **200**>

[0101] FIG. **11** is a flow-chart showing the manufacturing method of the second quartz-crystal vibrating device **200**. In FIG. **11**, the protocol T**20** for manufacturing the quartz-crystal frame **20**, the protocol T**21** for manufacturing the package lid **21** and the protocol T**22** for manufacturing the package base **22** can be carried out separately or in parallel. FIG. **12** is a plan view of the quartz-crystal wafer **20**W in the second embodiment, FIG. **13** is a plan view of the lid wafer **21**W in the second embodiment and FIG. **14** is a plan view of the base wafer **22**W in the second embodiment.

[0102] In protocol T**20**, the quartz-crystal frame **20** is manufactured. Protocol T**20** includes steps T**201** to T**203**.

[0103] In step T**201**, a quartz-crystal wafer **20**W, mirror-polished on both sides is prepared.

[0104] In step T**202**, as shown in FIG. **12**, outlines of a plurality of quartz-crystal frames **20** are formed on the quartz-crystal wafer **20**W, uniformly planar plate of quartz-crystal material, by etching. Thus, the quartz-crystal vibrating portion **27**, the outer frame **25** and the gap portion **23** are formed. Rounded-rectangular quartz-crystal through-holes CH are formed simultaneously on each quartz-crystal frame **20** on opposite ends in the X-axis direction. When a quartz-crystal through-hole CH is divided in half, it forms one quartz-crystal castellation **204** (refer to FIG. **8**).

[0105] In step T**203**, the first surface Me and the second surface Mi of the outer frame **25** are etched or sand-blasted, roughening first surface by Ra 10 μm to Ra 40 μm (refer to FIG. **9**).

[0106] In step T**204**, a metal layer is formed on both surfaces of the quartz-crystal wafer **20**W and quartz-crystal through-holes CH by sputtering or vacuum-deposition. Next, a photoresist is uniformly applied on entire surface of the metal layer. Using an exposure tool (not shown), exposed patterns of the excitation electrodes **201***a* and **201***b*, extraction electrodes **202***a* and **202***b*, metal film AC**12** and AC**21**, and quartz-crystal side surface electrodes **203***a* and **203***b*, are exposed onto the quartz-crystal wafer **20**W. Next, the metal layer exposed from photoresist is etched. Thus, shown in FIGS. **8** and **9**, the excitation electrodes **201***a* and **201***b*, extraction electrodes **202***a* and **202***b*, and metal films AC**12** and AC**21** are formed on both surfaces of the quartz-crystal wafer **20**W, and the quartz-crystal side surface electrodes **203***a* and **203***b* are formed on the quartz-crystal through-holes CH.

[0107] In protocol T**21**, the package lid **21** is manufactured. Protocol T**21** includes steps T**211** to T**214**.

[0108] In step T**211**, a lid wafer **21**W, having rough surface on both surfaces, is prepared. A half-finished lid wafer (not drawn), obtained by an AT-cut from a raw quartz-crystal, have sharp convexities and concavities on entire surface. If a half-finished lid wafer is used as it is, a rough surface with sharp convexities and concavities causes diffused reflection during the photoresist using the exposing tool (as processed in step S**213**, for example), thus making the formation of outlining difficult. Therefore, the half-finished lid wafer (not drawn), having rough surface of sharp convexities and concavities, is wet-etched. This makes the sharp convexities and concavities smooth, prevents diffused reflection, and allows forming the

exposing patterns more precisely. Although both surfaces of the lid wafer **21**W are wet-etched in step T**211**, it can be etched only on one side.

[0109] In step T**212**, as shown in FIG. **13**, several hundreds to several thousands of lid recesses **211** are formed on the lid wafer **21**W, a circular, uniformly planar plate of quartz-crystal material. The first peripheral surfaces M**1** are formed around the lid recesses **211**.

[0110] In step T**213**, the metal film AC**11** is formed on entire surface of the first peripheral surface M**1** by sputtering and etching, a same method as used in step T**203**.

[0111] In step T**214**, as shown in FIG. **13**, a low-melting-point glass LG is imprinted of the metal film AC**11** formed on the first peripheral surface M**1** of the lid wafer **21**W by screen-printing. The low-melting-point glass LG is not formed on the corresponding position **212**, corresponding to the quartz-crystal through-holes CH (quartz-crystal castellations **204**).

[0112] In protocol T**22**, the package base **22** is manufactured. Protocol T**22** includes steps T**221** to T**224**.

[0113] In step T**221**, as similar to step T**211**, a base wafer **22**W having rough surface on both surfaces is prepared.

[0114] In step T**222**, as shown in FIG. **14**, several hundreds to several thousands of base recesses **221** are formed on the base wafer **22**W, a uniformly thick, planar quartz-crystal plate. The second peripheral surface M**2** is formed surrounding the base recess **221**. Also the rounded-rectangular through-holes BH are formed on each end of the package base **22** in both X-axis directions. The base through-holes BH extend depthwise through the base wafer **22**W. When a base through-hole BH is divided in half, it forms one base castellation **224** (refer to FIG. **8**).

[0115] In step T**223**, the metal film AC**22** is formed on the second peripheral surface M**2** by sputtering and etching (same method as used in step T**203**). The base side surface electrodes **223***a* and **223***b* are formed on the base through-holes BH, and the external electrodes **222***a* and **222***b* are formed on the mounting surface (mounting surface of the piezoelectric device) of the base wafer **22**W.

[0116] In step T**224**, as shown in FIG. **14**, the low-melting-point glass LG is imprinted on the metal film AC**22** formed on the second peripheral surface M**2** of the base wafer **22**W, by screen-printing.

[0117] In step T**23**, the low-melting-point glass LG is heated and the quartz-crystal wafer **20**W and the base wafer **22**W are compressed against each other. The quartz-crystal wafer **20**W and the base wafer **22**W are bonded via the low-melting-point glass LG.

[0118] In step T**24**, a pair of connecting electrodes **14***a* and **14***b* is formed, so as to cover the external electrodes **222***a* and **222***b*, the base side surface electrodes **223***a* and **223***b*, and the quartz-crystal side surface electrodes **203***a* and **203***b*. Specifically, the bonded quartz-crystal wafer **20**W and the base wafer **22**W are placed on the table (not shown), with the quartz-crystal wafer **20**W facing downward. Then, a mask (not drawn) with openings formed on the corresponding position to the external electrodes **222***a* and **222***b*, and the base through-holes BH is disposed onto the mounting surface side of the base wafer **22**W. The connecting electrodes **14***a* and **14***b* are formed by sputtering or vacuum-deposition. Thus, the base side surface electrodes **223***a* and **223***b* formed in step T**223**, and the quartz-crystal side surface electrodes **203***a* and **203***b* formed in step T**203** are ensured to be electrically connected (refer to FIG. **9**).

[0119] In step T**25**, a low-melting-point glass LG is heated, and the lid wafer **21**W and quartz-crystal wafer **20**W are compressed against each other. The lid wafer **21**W is bonded onto the first surface Me of the quartz-crystal wafer **20**W via low-melting-point glass LG.

[0120] In step T**26**, the bonded lid wafer **21**W, the quartz-crystal wafer **20**W and the base wafer **22**W is cut into individual separate pieces. The second quartz-crystal vibrating device **200** is separated into individual pieces by cutting along scribe lines SL, denoted by dot-dash lines in FIGS. **12** to **14**, using a dicing unit such as a laser beam or a dicing saw. Thus, several hundreds to several thousands of the second quartz-crystal vibrating devices **200** are produced.

[0121] In the manufacturing method of the second quartz-crystal vibrating device **200** explained in FIG. **11**, although the low-melting-point glass LG is formed on the lid wafer **21**W and the base wafer **22**W, it can be formed on both surfaces of the quartz-crystal wafer **20**W.

INDUSTRIAL APPLICABILITY

[0122] Representative embodiments are described in detail above; however, as will be evident to those skilled in the relevant art, the present invention may be changed or modified in various ways within its technical scope. For example, the present disclosure may be directed to piezoelectric oscillators in which an IC accommodating an oscillating circuit is mounted inside the package on the package base. In this specification, although the various embodiments have been described in the context of AT-cut quartz-crystal vibrating pieces, the present disclosure may be directed to tuning-fork type piezoelectric vibrating pieces.

[0123] If the package lid or package base is fabricated by quartz-crystal material, an AT-cut quartz-crystal material or Z-cut quartz-crystal material can be used.

[0124] Furthermore, although low-melting-point glasses are used as a sealing material, it can be replaced with polyimide resin. If the polyimide resin is used as a sealing material, a polyimide resin can be applied to the predetermined region by screen-printing, or it can be exposed after applying photosensitive polyimide resin on entire surface.

What is claimed is:

1. A piezoelectric device for storing a piezoelectric vibrating piece which vibrates when an electrical voltage is applied, comprising:

a package lid, having a first peripheral surface formed circumferentially on a plane in a predetermined width; and

a package base, comprising a second peripheral surface bonded to the first peripheral surface of the package lid and a recess portion recessed from the second peripheral surface;

wherein at least one of the first peripheral surface of the package lid or the second peripheral surface of the package base have a rough surface;

a metal film is formed on the rough surface formed at least one of the package lid or the package base; and

the package lid and the package base are bonded using a sealing material disposed on the metal film.

2. The piezoelectric device of claim **1**, wherein the piezoelectric vibrating piece is made of a piezoelectric material; and

the rough surface is formed rougher than a first surface of the piezoelectric material.

3. The piezoelectric device of claim **1**, wherein the second peripheral surface of the package base is formed wider than the predetermined width;

the piezoelectric vibrating piece is mounted onto the second peripheral surface of the package base using an electrically conductive adhesive; and

the metal film is formed only on a bonding region of the second peripheral surface where the first peripheral surface and the second peripheral surface bond together.

4. The piezoelectric device of claim **2**, wherein the second peripheral surface of the package base is formed wider than the predetermined width;

the piezoelectric vibrating piece is mounted onto the second peripheral surface of the package base using an electrically conductive adhesive; and

the metal film is formed only on a bonding region of the second peripheral surface where the first peripheral surface and the second peripheral surface bond together.

5. The piezoelectric device of claim **3**, wherein the rough surface is only formed on the bonding region of the second peripheral surface.

6. The piezoelectric device of claim **1**, wherein the first peripheral surface of the package lid and the second peripheral surface of the package base have same width; and

the piezoelectric vibrating piece is mounted inside and onto the recess using the electrically conductive adhesive.

7. The piezoelectric device of claim **1**, wherein a pair of through-holes is formed on the package base, which extend depthwise through the package base.

8. A piezoelectric device, comprising:

a piezoelectric frame having a piezoelectric vibrating piece that vibrates when electrically energized and an outer frame including a first principal surface and a second principal surface formed as to surround the piezoelectric vibrating piece and;

a package lid having a first peripheral surface that is bonded to the first principal surface of the outer frame of the piezoelectric frame; and

a package base having a second peripheral surface that is bonded to the second principal surface of the outer frame of the piezoelectric frame;

wherein at least one of the first principal surface of the outer frame or the first peripheral surface of the package lid, and at least one of the second principal surface of the outer frame or the second peripheral surface of the package base has a rough surface;

a metal film is formed on the rough surface; and

the package lid and the outer frame, and the outer frame and the package base are bonded using a sealing material formed between metal films formed at least one of the package lid, the package base or the outer flame.

9. The piezoelectric device of claim **8**, wherein:

a pair of first castellations are formed on opposite peripheral edges of the outer frame of the piezoelectric frame, and a pair of second castellations are formed on opposite peripheral edges of the package base in positions that correspond to the respective first castellations while bonding the piezoelectric frame and the package base;

the piezoelectric frame comprises: a pair of excitation electrodes formed on the first principal surface and the second principal surface of the piezoelectric vibrating piece;

a first extraction electrode on the first principal surface extending from the excitation electrode on the first principal surface to the first castellation; a second extraction electrode on the second principal surface extending from the excitation electrode on the second principal surface to the first castellation; and

a first side surface electrode that is electrically connected to the first extraction electrode and formed on the first castellation;

wherein the package base comprises a pair of second side surface electrodes that is electrically connected to the first side surface electrode or the second extraction electrode and formed on the pair of second castellations; and

wherein a pair of connecting electrodes is formed on the first castellations and the second castellations, which electrically connects the first side surface electrode or the first extraction electrode to the second side surface electrode.

10. The piezoelectric device of claim **1**, wherein the sealing material includes a glass that melts at temperature between 350° C. and 410° C. or a polyimide resin.

11. The piezoelectric device of claim **1**, wherein the package lid and the package base is made of a glass or a piezoelectric material.

12. A method for manufacturing a piezoelectric device, comprising:

a first preparation step of preparing a piezoelectric vibrating piece that vibrates when electrically energized;

a second preparation step of preparing a lid wafer, including a plurality of package lids each having a first peripheral surface formed circumferentially on a plane in a predetermined width;

a first metal film forming step for forming a first metal film on a rough surface formed on the lid wafer;

a third preparation step of preparing a base wafer, including a plurality of package bases each having a second peripheral surface and a recess portion recessed from the second peripheral surface;

a second metal film forming step for forming a second metal film on a rough surface formed on the base wafer;

a mounting step for mounting the piezoelectric vibrating piece onto the package base using an electrically conductive adhesive; and

a bonding step for bonding the lid wafer and the base wafer using a sealing material between said respective first and second metal films.

13. The piezoelectric device of claim **12**, wherein the rough surfaces on the lid wafer and the base wafer are formed by sand-blasting or etching.

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