VIBRATION DEVICE, ELECTRONIC APPARATUS AND MOVING OBJECT

BACKGROUND

1. Technical Field

The present invention relates to a vibration device, an electronic apparatus and a moving object which include the vibration device.

2. Related Art

In the related art, a piezoelectric device, which includes a piezoelectric vibration element, a temperature sensing component, and a container having a first containing section containing the piezoelectric vibration element, and a second containing section containing a temperature sensing component, is known as an example of a vibration device (for example, JP-A-2013-102315). The container includes a first insulating substrate having a penetration hole configuring the second containing section and a plurality of mounting terminals on a bottom section; a second insulating substrate which is stacked on and fixed to the first insulating substrate, has a first electrode pad for mounting the piezoelectric vibration element on a surface, and has a second electrode pad for mounting the piezoelectric vibration element on a back surface; and a third insulating substrate which is stacked on and fixed to a surface of the second insulating substrate, and configures the first containing section.

In the piezoelectric device, at least one mounting terminal and the first electrode pad are electrically coupled to each other by a first thermal conduction section and a first wiring pattern, and at least another mounting terminal and the second electrode pad are electrically coupled to each other by a second thermal conduction section and a second wiring pattern. Thus, it is possible to reduce a temperature difference between temperature of the piezoelectric vibration element and temperature which is sensed by the temperature sensing component, and to obtain better frequency temperature characteristics.

In recent years, a vibration device represented by the piezoelectric device or the like which is used for an electronic apparatus, particularly a wireless communication apparatus such as a cellular phone having a GPS function is required to be more accurate.

Due to this, the piezoelectric device needs to be improved to obtain excellent frequency temperature characteristics and to further reduce a temperature difference between temperature of piezoelectric vibration element and temperature which is sensed by a temperature sensing component.

SUMMARY

The invention can be realized by the following aspects or application examples.

Application Example 1

According to this application example, there is provided a vibration device including a vibration piece; an electronic element; and a substrate including a first main surface and a second main surface which are respectively a front surface and a back surface, in which the vibration piece is mounted on a first mounting surface on the first main surface of the substrate, in which the electronic element is mounted on a second mounting surface on the second main surface of the substrate, in which the substrate has an overlapping section in which at least a portion of the first mounting surface overlaps at least a portion of the second mounting surface in planar view, and in which a thickness of the overlapping section is equal to or greater than 0.04 mm and less than 0.10 mm.

According to this, the vibration device includes the overlapping section in which at least a portion of the first mounting surface overlaps at least a portion of the second mounting surface. The vibration piece and the electronic element in the substrate are mounted on the first mounting surface and the second mounting surface. Since the thickness of the overlapping section is equal to or greater than 0.04 mm and less than 0.10 mm, thermal conduction between the vibration piece and the electronic element through the substrate is promoted.

As a result, for example, if the electronic element is a temperature sensing element, the vibration device can reduce a temperature difference between temperature of the vibration piece and temperature which is sensed by the temperature sensing element, and can obtain excellent frequency temperature characteristics.

　 Accordingly, a variation width of the frequency is decreased, and thus, the vibration device can be accurate.

Application Example 2

In the vibration device according to the application example, it is preferable that the thickness of the overlapping section is equal to or greater than 0.04 mm and equal to or less than 0.08 mm.

According to this, since the thickness of the overlapping section is equal to or greater than 0.04 mm and equal to or less than 0.08 mm, the vibration device can further promote thermal conduction between the vibration piece and the electronic element through the substrate.

Application Example 3

In the vibration device according to the application example, it is preferable that the thickness of the overlapping section is equal to or greater than 0.04 mm and equal to or less than 0.06 mm.

According to this, since the thickness of the overlapping section is equal to or greater than 0.04 mm and equal to or less than 0.06 mm, the vibration device can further promote thermal conduction between the vibration piece and the electronic element through the substrate.

Application Example 4

In the vibration device according to the application example, it is preferable that the substrate has a stacked structure in which the first main surface has a first layer with a thickness equal to or greater than 0.04 mm and less than 0.10 mm and the second main surface has a second layer with a thickness equal to or greater than that of the first layer, that the first mounting surface and the second mounting surface are respectively the front surface and the back surface of the first layer, that the second layer has an opening larger than the electronic element in a planar view, and that the electronic element is contained in the opening.

According to this, in the vibration device, the substrate has a stacked structure in which the first main surface has a first layer with a thickness equal to or greater than 0.04 mm and less than 0.10 mm and the second main surface has a second layer with a thickness equal to or greater than that of the first layer, the first mounting surface and the second mounting surface are respectively the front surface and the back surface of the first layer, and the electronic element is contained in the opening of the second layer.

Accordingly, in the vibration device, since the first layer of the substrate is a flat plate shape, it is easy to manage the thickness to a value equal to or greater than 0.04 mm and less than 0.10 mm. In addition, as the second layer with a thickness equal to or greater than that of the first layer is stacked on the first layer, it is possible to ensure the strength of the substrate.

In addition, since the electronic element is contained in the opening of the second layer, the vibration device can be thinned over all while ensuring the strength of the substrate.

Application Example 5

In the vibration device according to the application example, it is preferable that the substrate is stacked on the first main surface of the first layer, and further includes a third layer of frame shape surrounding the vibration piece.

According to this, since the substrate is stacked on the first layer and further includes a third layer of frame shape surrounding the vibration piece, in the vibration device, the internal space (concave section) which contains the vibration piece on the substrate is provided, and it is possible to further increase the strength of the substrate.

Application Example 6

In the vibration device according to the application example, it is preferable that at least the overlapping section of the substrate uses aluminum nitride or silicon carbide as main components.

According to this, since at least overlapping section of the substrate uses aluminum nitride or silicon carbide as main components, the vibration device has a relatively high thermal conductivity among ceramic (also referred to as ceramics) materials.

As a result, since thermal conduction between the vibration piece and the electronic element through the substrate is further promoted, for example, if the electronic element is the temperature sensing element, the vibration device can further reduce the temperature difference between the temperature of the vibration piece and the temperature which is sensed by the temperature sensing element, and can obtain more excellent frequency temperature characteristics.

Application Example 7

In the vibration device according to the application example, it is preferable that the electronic element is a temperature sensing element.

According to this, since the electronic element is the temperature sensing element, the vibration device can reduce the temperature difference between temperature of the vibration piece and temperature which is sensed by the temperature sensing element, and can obtain excellent frequency temperature characteristics.

Application Example 8

In the vibration device according to the application example, it is preferable that the temperature sensing element is a thermistor or a semiconductor element for temperature measurement.

According to this, since the temperature sensing element is the thermistor or the semiconductor element for temperature measurement, the vibration device can accurately sense the surrounding temperature using the characteristics of the thermistor and the semiconductor element for temperature measurement.

Application Example 9

According to this application example, there is provided an electronic apparatus including the vibration device described in any one of the application examples.

According to this, since the electronic apparatus of the present configuration includes the vibration device described in any one of the application examples, the electronic apparatus can obtain the effect which is described in any one of the application examples and obtain excellent performance.

Application Example 10

According to this application example, there is provided a moving object including the vibration device described in any one of the application examples.

According to this, since the moving object of the present configuration includes the vibration device described in any one of the application examples, the moving object can obtain the effect which is described in any one of the application examples and obtain excellent performance.

BRIEF DESCRIPTION OF THE DRAWINGS

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

Figs. 1A to 1C are schematic views illustrating a schematic configuration of a crystal vibrator according to a first embodiment, Fig. 1A is a plan view viewed from a lid side, Fig. 1B is a sectional view taken along line IB-IB of Fig. 1A, and Fig. 1C is a plan view viewed from a bottom surface side.

Fig. 2 is a circuit diagram relating to driving of a crystal vibrator including a temperature sensing element serving as an electronic element which is contained in the crystal vibrator according to the first embodiment.

Fig. 3 is a graph illustrating a relationship between a thickness t of a package base and a temperature difference between a first mounting surface side and a second mounting surface side.

Fig. 4 is a diagram illustrating a relationship between the thickness t of the package base and a mechanical strength.

Fig. 5 is a graph illustrating a relationship between the thickness t of the package base and yield of frequency temperature characteristics of the crystal vibrator.

Figs. 6A to 6C are schematic views illustrating a schematic configuration of a crystal vibrator according to a modification example of a first embodiment, Fig. 6A is a plan view viewed from a lid side, Fig. 6B is a sectional view taken along line VIB-VIB of Fig. 6A, and Fig. 6C is a plan view viewed from a bottom surface side.

Figs. 7A to 7C are schematic views illustrating a schematic configuration of a crystal vibrator according to a second embodiment, Fig. 7A is a plan view viewed from a lid side, Fig. 7B is a sectional view taken along line VIIB-VIIB of Fig. 7A, and Fig. 7C is a plan view viewed from a bottom surface side.

Fig. 8 is a schematic perspective view illustrating a cellular phone serving as an electronic apparatus.

Fig. 9 is a schematic perspective view illustrating an automobile serving as a moving object.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

Hereinafter, embodiments in which the present invention is specified will be described with reference to the drawings

First Embodiment

First of all, a crystal vibrator which is an example of a vibration device will be described.

Figs. 1A to 1C are schematic views illustrating a schematic configuration of a crystal vibrator according to a first embodiment, Fig. 1A is a plan view viewed from a lid side, Fig. 1B is a sectional view taken along line IB-IB of Fig. 1A, and Fig. 1C is a plan view viewed from a bottom surface side. Lid is omitted in the following plan view which is viewed from a lid side and includes Fig. 1A. In addition, for the sake of clarity, a size ratio of each configuration element is different from an actual size ratio.

Fig. 2 is a circuit diagram relating to driving of a crystal vibrator including a temperature sensing element contained in the crystal vibrator according to the first embodiment.

As illustrated in Fig. 1A to 1C, a crystal vibrator 1 includes a crystal vibration piece 10 serving as a vibration piece, a thermistor 20 which is an example of a temperature sensing element serving as an electronic element, and a package 30 in which the crystal vibration piece 10 and the thermistor 20 are contained.

The crystal vibration piece 10 is an AT-cut crystal substrate which is obtained by cutting a rough crystal or the like at a predetermined angle, in which a plane shape is formed in a substantially rectangular shape, and which has a vibration section 11 in which thickness shear vibration is excited and a base section 12 which is coupled to the vibration section 11, as one piece.

In the crystal vibration piece 10, protrusion electrodes 15a and 16a, which protrude from excitation electrodes 15 and 16 of a substantially rectangular shape that are formed on one main surface 13 of the vibration section 11 and on the other main surface 14 of the vibration section 11, are formed on the base section 12.

The protrusion electrode 15a protrudes from the excitation electrode 15 of the one main surface 13 toward the base section 12 along a length direction (left-right direction of a sheet surface) of the crystal vibration piece 10, is roundly input to the other main surface 14 along a side surface of the base section 12, and extends to the other main surface 14 of the base section 12.

The protrusion electrode 16a protrudes from the excitation electrode 16 of the other main surface 14 toward the base section 12 along a length direction of the crystal vibration piece 10, is roundly input to the one main surface 13 along a side surface of the base section 12, and extends to the one main surface 13 of the base section 12.

For example, the excitation electrodes 15 and 16 and the protrusion electrodes 15a and 16a are formed of a metal-coated film having a configuration in which a base layer is formed of, for example, Cr (chrome), and Au (gold) or a metal that uses Au as main components is stacked on the base layer.

The thermistor 20 is, for example, a temperature sensing element (temperature sensing resistance element) of a chip type (rectangular shape), has electrodes 21 and 22 in both end sections thereof, and is a resistance body having a great change of electric resistance with respect to a temperature change.

For example, a thermistor, which is called a negative temperature coefficient (NTC) thermistor in which resistance decreases with respect to an increase of temperature, is used for the thermistor 20. Since a relationship between changes of temperature and a resistance value is linear, the NTC thermistor is frequently used as a temperature sensor.

The thermistor 20 is contained in the package 30, senses a temperature around the crystal vibration piece 10, and thereby performs a function of contributing to correction of a frequency variation according to temperature change of the crystal vibration piece 10 as a temperature sensor.

The package 30 has a substantially flat plate shape whose plane shape is substantially rectangular, includes a package base 31 which is a substrate having a first main surface 33 and a second main surface 34 that respectively form a front surface and a back surface, and a lid 32 of a flat shape which covers the first main surface 33 side of the package base 31, and is formed in a substantially rectangular shape.

The package base 31 has a stacked structure that includes a first layer 31a of a flat shape in which a surface of the first main surface 33 side becomes a first mounting surface J1 and a surface of the second main surface 34 side becomes a second mounting surface J2, a second layer 31b which has an opening in a central portion thereof, is stacked on a second mounting surface J2 of the first layer 31a, and has a side opposite to the stacked surface becoming the second main surface 34, and a third layer 31c of a frame shape which is stacked on the first mounting surface J1 of the first layer 31a and has a surface of the lid 32 side becoming the first main surface 33.

The first mounting surface J1 and the second mounting surface J2 of the first layer 31a respectively form a front surface and a back surface, the crystal vibration piece 10 is mounted in the first mounting surface J1, and the thermistor 20 is mounted in the second mounting surface J2.

A ceramic-based insulating material, such as, an aluminum oxide sintered body in which a ceramic green sheet is formed, stacked, and baked, a mullite sintered body, an aluminum nitride sintered body, a silicon carbide sintered body, or a glass ceramic sintered body, crystal, glass, silicon (silicon with a high resistance), or the like is used for the first layer 31a and the second layer 31b of the package base 31.

An aluminum nitride sintered body or a silicon carbide sintered body, that uses aluminum nitride (thermal conductivity: approximately 150 to 280 W/(m×k)) or silicon carbide (thermal conductivity: approximately 100 to 350 W/(m×k)) as main components, and that has a relatively high thermal conductivity among the ceramic-based insulating materials, is used for the first layer 31a and the second layer 31b of the package base 31, and this is preferred from a viewpoint of promotion of thermal conduction of the package base 31.

The first layer 31a of the package base 31 is formed of a flat shape, and it is preferable that a thickness thereof is equal to or greater than 0.04 mm and less than 0.10 mm. It is more preferable that the thickness thereof is equal to or greater than 0.04 mm and equal to or less than 0.08 mm. It is further more preferable that the thickness thereof is equal to or greater than 0.04 mm and equal to or less than 0.06 mm.

The second layer 31b is formed of a flat shape having an opening, and it is preferable that a thickness thereof is equal to or greater than that of the first layer 31a. It is more preferable that the thickness thereof is less than 0.30 mm. In addition, the opening of the second layer 31b is formed more largely than the thermistor 20 in a planar view.

The third layer 31c and the lid 32 use the same materials as the first layer 31a and the second layer 31b, or a metal such as kovar or 42 alloy. The third layer 31c has a frame shape surrounding the crystal vibration piece 10, and it is preferable that a thickness thereof is greater than that of the crystal vibration piece 10.

In other words, the package base 31 has an overlapping section (here, the first layer 31a) in which at least a portion of the first mounting surface J1 overlaps at least a portion of the second mounting surface J2 in a planar view, and it is preferable that a thickness of the overlapping section is equal to or greater than 0.04 mm and less than 0.10 mm. It is more preferable that the thickness of the overlapping section is equal to or greater than 0.04 mm and equal to or less than 0.08 mm. It is further more preferable that the thickness of the overlapping section is equal to or greater than 0.04 mm and equal to or less than 0.06 mm.

Internal terminals J1a and J1b are provided at a position facing the protrusion electrodes 15a and 16a of the crystal vibration piece 10, in the first mounting surface J1 of the package base 31.

In the crystal vibration piece 10, the protrusion electrodes 15a and 16a are bonded to the internal terminals J1a and J1b through a conductive adhesive 40 such as epoxy-base, silicone-base, or polyimide-base to which a conductive material such as a metal filler is mixed.

As a result, the crystal vibration piece 10 is mounted on the first mounting surface J1 of the first main surface 33 side of the package base 31 in a state of being surrounded by the third layer 31c of the package base 31.

In the crystal vibrator 1, in a state in which the crystal vibration piece 10 is bonded to the internal terminals J1a and J1b of the package base 31, the third layer 31c of the package base 31 is covered with the lid 32, the package base 31 and the lid 32 are bonded together by a bonding member such as seam welding, low-melting-point glass, or adhesive, and thereby an internal space S including the first layer 31a of the package base 31, the third layer 31c, and the lid 32 is sealed in an airtight manner.

Figs. 1A to 1C illustrate a state in which the third layer 31c formed by a metal and the lid 32 formed by a metal are bonded together by seam welding, as an example. In this case, the third layer 31c is soldered to a metallization layer (not illustrated) provided in a peripheral portion of the first layer 31a.

The internal space S which is sealed in an airtight manner in the package 30 is in a decompressed vacuum state (state of a high degree of vacuum) or is filled with inert gas, such as, nitride, helium or argon. It is preferable that the internal space S is filled with the inert gas, such as, nitride, helium or argon rather than a vacuum state, in order to promote thermal conduction from the lid 32 to the crystal vibration piece 10.

A concave section 35 is provided in the second main surface 34 side of the package base 31 by the opening of the second layer 31b and the second mounting surface J2 of the first layer 31a. A plane shape of the concave section 35 is formed of, for example, a track shape.

Electrode pads J2a and J2b are provided at a position facing electrodes 21 and 22 of the thermistor 20, in the second mounting surface J2 which is a bottom surface of the concave section 35.

The electrodes 21 and 22 of the thermistor 20 are bonded to the electrode pads J2a and J2b through a bonding member 41 such as a conductive adhesive or solder. As a result, the thermistor 20 is mounted on the second mounting surface J2 on the second main surface 34 side of the package base 31, and is contained in the concave section 35 (in other words, opening of the second layer 31b).

A length direction (direction in which the electrode 21 and the electrode 22 are coupled to each other) of the thermistor 20 coincides with a length direction (left-right direction of a sheet surface) of the package base 31, and the thermistor 20 is disposed in a substantially central portion of the concave section 35.

Electrode terminals 37a, 37b, 37c, and 37d are respectively provided in four corners of the second main surface 34 of the package base 31.

The two electrode terminals 37b and 37d located at, for example, one diagonal line within the four electrode terminals 37a to 37d are coupled to the internal terminals J1a and J1b connected to the protrusion electrodes 15a and 16a of the crystal vibration piece 10 through conductive via lines (conductive electrodes which are obtained by filling through holes with a metal or a material with conductivity) V1 to V4 and internal wires P1 and P2 that respectively penetrate the first layer 31a and the second layer 31b of the package base 31.

The remaining two electrode terminals 37a and 37c located at the other diagonal line are coupled to electrode pads J2a and J2b connected to the electrodes 21 and 22 of the thermistor 20 through conductive via lines V5 and V6 and internal wires P3 and P4.

The four electrode terminals 37a to 37d are formed of a shape in which a plane shape is a rectangular shape and a part of the concave section 35 side is notched.

If the lid 32 and the third layer 31c of the package base 31 are a metal, the electrode terminal 37c is electrically coupled to the lid 32 through the third layer 31c by either the conductive via line V7 or a conductive film formed in a castellation (concave section, not illustrated) provided in a corner on the outside of the package base 31, and this is preferred from a viewpoint of improvement of shielding properties and promotion of thermal conduction. If the third layer 31c is insulating material, the conductive via line is also provided in the third layer 31c.

In addition, the electrode terminal 37c of the crystal vibrator 1 is grounded as an earth terminal (GND terminal), and thereby shielding properties can be further improved.

The internal terminals J1a and J1b, the electrode pads J2a and J2b, and the electrode terminals 37a to 37d are formed of a metal-coated film in which a metallization layer such as W (tungsten) or Mo (molybdenum) is coated with each coated film such as Ni (nickel) or Au to be stacked.

As illustrated in Fig. 2, in the crystal vibrator 1, for example, in response to a drive signal which is applied to the crystal vibrator 1 from an oscillation circuit 61 that is integrated in an IC chip 70 of an electronic apparatus through the electrode terminals 37b and 37d, the crystal vibration piece 10 excites thickness shear vibration to resonate (oscillate) at a predetermined frequency, and thus a resonance signal (oscillation signal) is output from the electrode terminals 37b and 37d.

At this time, the thermistor 20 senses a temperature around the crystal vibration piece 10 as a temperature sensor, the crystal vibrator 1 converts the sensed temperature into a change of a voltage value which is supplied from a power supply 62, and outputs the change as a detection signal from the electrode terminal 37a.

For example, the detection signal which is output is converted into a digital signal by an A/D converting circuit 63 that is integrated in the IC chip 70 of the electronic apparatus, and is input to a temperature compensating circuit 64 which is integrated in the IC chip 70 of the electronic apparatus, in the same manner. Thus, the temperature compensating circuit 64 outputs a correction signal based on temperature compensation data to the oscillation circuit 61 in response to the detection signal which is input.

The oscillation circuit 61 applies the drive signal which is compensated on the basis of the correction signal that is input to the crystal vibration piece 10, and compensates for the resonance frequency of the crystal vibration piece 10 which varies depending on a temperature change so as to be a predetermined frequency, The oscillation circuit 61 amplifies an oscillation signal with the compensated frequency and outputs the oscillation signal to the outside.

At this time, the smaller a temperature difference between the temperature of the crystal vibration piece 10 and the temperature which is sensed by the thermistor 20 is (the more correct the detection signal is), the more accurately the crystal vibrator 1 can correct the resonance frequency of the crystal vibration piece 10.

As a result, the crystal vibrator 1 can obtain excellent frequency temperature characteristics, and can be accurate.

As described above, the crystal vibrator 1 according to the first embodiment includes the overlapping section (here, the first layer 31a) in which at least a portion of the first mounting surface J1 and at least a portion of the second mounting surface J2 overlap each other in which the crystal vibration piece 10 and the thermistor 20 of the package base 31 are mounted, and since the thickness t (hereinafter, simply referred to as thickness t) of the overlapping section is equal to or greater than 0.04 mm and less than 0.10 mm, thermal conduction between the crystal vibration piece 10 and the thermistor 20 through the package base 31 is promoted.

As a result, the crystal vibrator 1 can reduce a temperature difference between the temperature of the crystal vibration piece 10 and the temperature which is sensed by the thermistor 20, and can obtain excellent frequency temperature characteristics.

Accordingly, since a variation width of the frequency is small, the crystal vibrator 1 can be accurate.

Here, the above description will be made in detail.

As a method of achieving a thermal equilibrium state (state in which both have the same temperature) between the crystal vibration piece 10 and the thermistor 20 of the crystal vibrator 1 at the time of being mounted in a main circuit board (mother board) of a wireless communication apparatus such as a cellular phone which is an electronic apparatus in a shorter period of time, a thermal capacity of a conduction member such as the conduction via lines V1 to V6 and the internal wires P1 to P4 can be approximately equal by a path of the electrode terminals 37b and 37d to the crystal vibration piece 10, and a path of the electrode terminals 37a and 37c to the thermistor 20, as described in JP-A-2013-102315.

The inventor sets the thickness t of the package base 31 to a value equal to or greater than 0.04 mm and less than 0.10 mm, based on an analysis result of simulation and experimentation which will be later, as a further improved method, and thereby while retaining a mechanical strength, a temperature difference between the temperature of the crystal vibration piece 10 and the temperature which is sensed by the thermistor 20 can be further reduced, and excellent frequency temperature characteristics can be obtained.

Fig. 3 is a graph illustrating a relationship between the thickness t of the package base and the temperature difference between the first mounting surface side and the second mounting surface side. The horizontal axis denotes the thickness t, and the vertical axis denotes of the value which comparatively figures a temperature difference between the first mounting surface side and the second mounting surface side such that the value is set to 1.00 when the thickness t is 0.20 mm. The vertical axis denotes that the greater the figures are, the greater the temperature difference increases, and the smaller the figures are, the smaller the temperature difference is.

As illustrated in Fig. 3, it can be seen that, as the thickness t of the package base 31 becomes thinner, the temperature difference between the first mounting surface J1 side and the second mounting surface J2 side becomes smaller.

Fig. 4 is a diagram illustrating a relationship between the thickness t of the package base and a mechanical strength.

Here, a bending resistant strength test (three point bending test) was performed based on “JIS R 1601 method of testing room temperature bending strength of fine ceramics”. As a test result, a three-step evaluation of A (good), B (acceptable), and C (not acceptable) was conducted based on a magnitude of maximum bending stress when the package base 31 is broken.

As illustrated in Fig. 4, it can be seen that sample 1 (t=0.01 mm) and sample 2 (t=0.02 mm) marks C and do not withstand actual use. Sample 3 (t=0.03 mm) marks B, but in view of variation and margin at the time of mass production, it is considered that there is a large risk for actual use.

Meanwhile, it can be seen that sample 4 (t=0.04 mm) and sample 5 (t=0.05 mm) marks A and sufficiently withstand actual use.

As a result, after further reducing a temperature difference between the temperature of the crystal vibration piece 10 and the temperature which is sensed by the thermistor 20, while retaining mechanical strength, a lower limit of the thickness t of the package base 31 is 0.04 mm.

Fig. 5 is a graph illustrating a relationship between the thickness t of the package base and yield of the frequency temperature characteristics of the crystal vibrator. The horizontal axis denotes the thickness t, and the vertical axis denotes yield of the frequency temperature characteristics of the crystal vibrator.

As illustrated in Fig. 5, it can be seen that the yield of the frequency temperature characteristics deteriorate in accordance with an increase of the thickness t of the package base 31 up to 0.10 mm and 0.11 mm exceeding 0.09 mm.

In this way, if the thickness t of the package base 31 increases up to 0.10 mm and 0.11 mm exceeding 0.09 mm, the temperature difference between the temperature of the crystal vibration piece 10 and the temperature which is sensed by the thermistor 20 increases, and thus correction of the resonance frequency of the crystal vibration piece 10 which is performed by the temperature compensating circuit 64 (refer to Fig. 2) becomes inaccurate.

As a result, the upper limit of the thickness t of the package base 31 for reducing the temperature difference between the temperature of the crystal vibration piece 10 and the temperature which is sensed by the thermistor 20 and after obtaining better frequency temperature characteristics at a high yield is a value less than 0.10 mm.

In addition, in the crystal vibrator 1, if the thickness t of the package base 31 is equal to or greater than 0.04 mm and equal to or less than 0.08 mm, thermal conduction between the crystal vibration piece 10 and the thermistor 20 through the package base 31 will be further promoted.

In addition, in the crystal vibrator 1, if the thickness t of the package base 31 is equal to or greater than 0.04 mm and equal to or less than 0.06 mm, thermal conduction between the crystal vibration piece 10 and the thermistor 20 through the package base 31 will be further promoted.

In addition, the crystal vibrator 1 has a stacked structure in which the package base 31 has the first layer 31a with a thickness equal to or greater than 0.04 mm and less than 0.10 mm on the first main surface 33 side, and the second layer 31b with a thickness equal to or greater than that of the first layer 31a on the second main surface 34 side. The first mounting surface J1 and the second mounting surface J2 respectively are a front surface and a back surface of the first layer 31a, and the thermistor 20 is contained in the opening of the second layer 31b.

As a result, in the crystal vibrator 1, since the first layer 31a of the package base 31 is a flat plate shape, it is easy to manage the thickness t in a range equal to or greater than 0.04 mm and less than 0.10 mm. In addition, since the second layer 31b with a thickness equal to or greater than that of the first layer 31a is stacked on the first layer 31a, it is possible to ensure the strength of the package base 31.

In addition, since the thermistor 20 is contained in the opening (concave section 35) of the second layer 31b, whole crystal vibrator 1 can be thinned while ensuring the strength of the package base 31.

In addition, since the package base 31 is stacked on the first layer 31a and further includes the third layer 31c having a frame shape surrounding the crystal vibration piece 10, the crystal vibrator 1 provided with the internal space S (concave section configuring the internal space S) which contains the crystal vibration piece 10 in the package base 31, and it is possible to further increase the strength of the package base 31.

In addition, the crystal vibrator 1 uses, for example, an aluminum nitride sintered body or a silicon carbide sintered body which contains aluminum nitride (thermal conductivity: approximately 150 W/(m×K) to 280 W/(m×K)) or silicon carbide (thermal conductivity: approximately 100 W/(m×K) to 350 W/(m×K)) which have relatively high thermal conductivity even among ceramic-based insulating materials, as main components for the first layer 31a and the second layer 31b of the package base 31. In other words, at least the overlapping section of the package base 31 contains aluminum nitride or silicon carbide as main components.

As a result, in the crystal vibrator 1, since thermal conduction between the crystal vibration piece 10 and the thermistor 20 through the package base 31 is further promoted, it is possible to further reduce (close to a thermal equilibrium state) the temperature difference between the temperature of the crystal vibration piece 10 and the temperature which is sensed by the thermistor 20, and to obtain more excellent frequency temperature characteristics.

As a result, the crystal vibrator 1 can be more accurate.

In addition, in the crystal vibrator 1, since the electronic element is a temperature sensing element, it is possible to reduce the temperature difference between the temperature of the crystal vibration piece 10 and the temperature which is sensed by the temperature sensing element, and to obtain excellent frequency temperature characteristics.

In addition, since the temperature sensing element is the thermistor 20, the crystal vibrator 1 can correctly sense the surrounding temperature using the characteristics of the thermistor 20.

A semiconductor element for temperature measurement may be used as the temperature sensing element instead of the thermistor 20, and it is possible to correctly sense the surrounding temperature using characteristics of the semiconductor element for temperature measurement. A diode or a transistor can be used as the semiconductor element for temperature measurement.

In detail, in a case of a diode, using forward characteristics of the diode in which a constant current flows from an anode terminal to a cathode terminal, a forward voltage which changed depending on temperature is measured, and thus the temperature can be sensed. In addition, in a case of a transistor, the transistor functions as a diode by coupling a base to a collector, and thus temperature can be sensed in the same manner as described above.

As a diode or a transistor is used for a temperature sensing element, it is possible to suppress superposition of noise in the crystal vibrator 1.

In the crystal vibrator 1, if the package base 31 does not have a structure in which the first layer 31a, the second layer 31b, and the third layer 31c are stacked and instead, is formed of one piece, the overlapping section of the first mounting surface J1 and the second mounting surface J2 of the package base 31 is positioned in the inside of the concave section 35 in a planar view.

Modification Example

Subsequently, a modification example of the first embodiment will be described.

Figs. 6A to 6C are schematic views illustrating a schematic configuration of a crystal vibrator according to a modification example of the first embodiment, Fig. 6A is a plan view viewed from a lid side, Fig. 6B is a sectional view taken along line VIB-VIB of Fig. 6A, and Fig. 6C is a plan view viewed from a bottom surface side.

The same symbols or reference numerals are attached to the same portions as those of the first embodiment, and description thereof will be omitted. Description will be focused on portions different from that of the first embodiment.

As illustrated in Figs. 6A to 6C, a crystal vibrator 2 according to the modification example is different from that of the first embodiment in a disposition direction of the thermistor 20.

In the crystal vibrator 2, the thermistor 20 is disposed in such a manner that a length direction (direction in which the electrode 21 is coupled to the electrode 22) of the thermistor 20 intersects with (here, orthogonal to) a length direction (left-right direction of a sheet surface) of the package base 31.

As a result, the crystal vibrator 2 can suppress a decrease of fixing strength (bonding strength) of the thermistor 20 associated with bending of the package base 31 in which bending in a length direction is large on a trend basis, in addition to the effects of the first embodiment.

A configuration of the modification example can also be applied to the following embodiment.

Second Embodiment

Subsequently, another configuration of a crystal vibrator serving as a vibration device will be described.

Figs. 7A to 7C are schematic views illustrating a schematic configuration of a crystal vibrator according to a second embodiment, Fig. 7A is a plan view viewed from a lid side, Fig. 7B is a sectional view taken along line VIIB-VIIB of Fig. 7A, and Fig. 7C is a plan view viewed from a bottom surface side.

The same symbols or reference numerals are attached to the same portions as those of the first embodiment, and description thereof will be omitted. Description will be focused on portions different from that of the first embodiment.

As illustrated in Figs. 7A to 7C, a crystal vibrator 3 according to the second embodiment is different from that of the first embodiment in configurations of the package base 31 and the lid 32.

In the crystal vibrator 3, the third layer 31c of the package base 31 is removed, and instead, the lid 32 and a bonding member 39 are disposed. Accordingly, the crystal vibrator 3 has the package base 31 where the first main surface 33 and the first mounting surface J1are the same surface.

The lid 32 is formed in a cap shape in which a flange section 32a is provided in the entire periphery, using a metal such as, Kovar or 42 alloy.

The crystal vibrator 3 ensures the internal space S which contains the crystal vibration piece 10 by bulge of a cap portion of the lid 32.

The flange section 32a of the lid 32 is coupled to the first main surface 33 (first mounting surface J1) of the package base 31 through the bonding member 39 with conductivity that a seam ring, a brazing material, a conductive adhesive, or the like has.

Accordingly, the lid 32 is electrically coupled to the electrode terminal 37c through the conductive via lines V6 and V7, and the internal wire P4 in the package base 31 to obtain shield effects and to promote thermal conduction.

The lid 32 is electrically coupled to the bonding member 39 and the electrode terminal 37c through a conductive film formed in a castellation (not illustrated) provided on a corner of the outside of the package base 31.

As described above, since the third layer 31c of the package base 31 is removed from the crystal vibrator 3 according to the second embodiment, manufacture of the package base 31 is easier than that of the first embodiment.

In the crystal vibrator 3, the lid 32 may be electrically coupled to the electrode terminal 37c, insofar as there is no hindrance to the promotion of shield and thermal conduction. As a result, the bonding member 39 may be a member having insulation properties.

Electronic Apparatus

Subsequently, a cellular phone will be described as an example of an electronic apparatus including the vibration device described above.

Fig. 8 is a schematic perspective view illustrating a cellular phone serving as an electronic apparatus.

A cellular phone 700 includes a crystal vibrator serving as the vibration device described in each embodiment and the modification example.

The cellular phone 700 illustrated in Fig. 8 uses the above-described crystal vibrator (any one of the crystal vibrators 1 to 3) as a timing device such as a reference clock generation source, and includes a liquid crystal display device 701, a plurality of operation buttons 702, a reception hole 703, and a transmission hole 704. A shape of the cellular phone is not limited to the illustrated type, and may be a shape of a so-called smart phone type.

The vibration device such as the above-described crystal vibrator is not limited to a cellular phone, and can be appropriately used as a timing device of an electronic apparatus including an electronic book, a personal computer, a television, a digital still camera, a video camera, a video recorder, a navigation device, a pager, an electronic organizer, an electronic calculator, a word processor, a workstation, a television phone, a POS terminal, a game machine, a medical device (for example, an electronic thermometer, a blood pressure meter, a blood glucose meter, an electrocardiogram measuring device, an ultrasonic diagnostic apparatus, an electronic endoscope), a fish finder, various measurement equipment, instruments, a flight simulator, or the like. In any cases, it is possible to obtain the effects described in each embodiment and the modification example described above, and to provide an electronic apparatus having excellent performance.

Moving Object

Subsequently, an automobile will be described as an example of a moving object including the vibration device described above.

Fig. 9 is a schematic perspective view illustrating an automobile serving as a moving object.

An automobile 800 includes a crystal vibrator serving as the vibration device described in each embodiments and the modification example described above.

The automobile 800 uses the above-described crystal vibrator (any one of the crystal vibrators 1 to 3) as a timing device such as a reference clock generation source of each electronic control type device (for example, an electronic control type fuel injection device, an electronic control type ABS device, an electronic control type constant speed traveling device, or the like) which is mounted.

According to this, including the above-described crystal vibrator, the automobile 800 can obtain the effects described in each embodiment and the modification example described above, and exert excellent performance.

The vibration device such as the above-descried crystal vibrator is not limited to the automobile 800, and can be appropriately used as a timing device such as a reference clock generation source of a moving object including a self-propelled robot, a self-propelled transport device, a train, a ship, an airplane, an artificial satellite, or the like. In any cases, it is possible to obtain the effects described in each embodiment and the modification example described above, and to provide a moving object having excellent performance.

The shape of the vibration piece of the crystal vibrator is not limited to a type of the illustrated flat plate shape, and may be a type (for example, convex type, bevel type, or mesa type) in which the central portion is thick and the peripheral portion is thin, a type (for example, reverse mesa type) in which the central portion is thin and the peripheral portion is thick, or a tuning fork shape.

A material of the vibration piece is not limited to crystal, and may be a semiconductor such as, lithium tantalate (LiTaO3), lithium tetraborate (Li2B4O7), lithium niobate (LiNbO3), lead zirconate titanate (PZT), zinc oxide (ZnO), a piezoelectric material such as aluminum nitride (AlN), or silicon (Si).

In addition, a driving method of thickness shear vibration may be electrostatic driving performed by coulomb’s force in addition to piezoelectric effect of a piezoelectric body.

What is claimed is:

1. A vibration device comprising:

a vibration piece;

an electronic element; and

a substrate including a first main surface and a second main surface which are respectively a front surface and a back surface,

wherein the vibration piece is mounted on a first mounting surface on the first main surface of the substrate,

wherein the electronic element is mounted on a second mounting surface on the second main surface of the substrate,

wherein the substrate has an overlapping section in which at least a portion of the first mounting surface overlaps at least a portion of the second mounting surface in planar view, and

wherein a thickness of the overlapping section is equal to or greater than 0.04 mm and less than 0.10 mm.

2. The vibration device according to Claim 1, wherein the thickness of the overlapping section is equal to or greater than 0.04 mm and equal to or less than 0.08 mm.

3. The vibration device according to Claim 1, wherein the thickness of the overlapping section is equal to or greater than 0.04 mm and equal to or less than 0.06 mm.

4. The vibration device according to Claim 1,

wherein the substrate has a stacked structure in which the first main surface has a first layer with a thickness equal to or greater than 0.4 mm and less than 0.10 mm and the second main surface has a second layer with a thickness equal to or greater than that of the first layer,

wherein the first mounting surface and the second mounting surface are respectively the front surface and the back surface of the first layer,

wherein the second layer has an opening larger than the electronic element in a planar view, and

wherein the electronic element is contained in the opening.

5. The vibration device according to Claim 4, wherein the substrate is stacked on the first main surface of the first layer, and further includes a third layer of frame shape surrounding the vibration piece.

6. The vibration device according to Claim 1, wherein at least the overlapping section of the substrate uses aluminum nitride or silicon carbide as main components.

7. The vibration device according to Claim 1, wherein the electronic element is a temperature sensing element.

8. The vibration device according to Claim 7, wherein the temperature sensing element is a thermistor or a semiconductor element for temperature measurement.

9. An electronic apparatus comprising:

the vibration device according to any one of Claims 1 to 8.

10. A moving object comprising:

the vibration device according to any one of Claims 1 to 8.

ABSTRACT

A crystal vibrator includes a crystal vibration piece, a thermistor, and a package base having a first main surface and a second main surface which are respectively a front surface and a back surface. The crystal vibration piece is mounted on the first mounting surface of the first main surface of the package base. The thermistor is mounted on the second mounting surface of the second main surface of the package base. The package base has an overlapping section in which at least a portion of the first mounting surface overlaps at least a portion of the second mounting surface in a planar view. A thickness of the overlapping section is equal to or greater than 0.04 mm and less than 0.10 mm.