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(54) QUARTZ CRYSTAL VIBRATOR

(71) We, KABUSHIKI KAISHA SUWA SEIKOSHA, a Japanese body corporate, of 3-4, 4-chome, Ginza, Chuo-ku, Tokyo, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to quartz crystal vibrators, e.g. for timepieces such as wrist watches.

In recent years, the technology of electronic wrist watches has developed considerably and quartz crystal wrist watches are now being manufactured. Such quartz crystal wrist watches have quartz crystal vibrators as their time standard. Conventional quartz crystal vibrators utilise the flexural mode of vibration and are of the free-free-bar type or the tuning fork type. Conventional vibrators are formed from natural quartz crystal material using a diamond wheel cutter or a supersonic or ultrasonic technique.

In most cases, the conventional vibrators are supported by having directly adhered to them electrically conductive supporting wires, e.g. lead wires and the like.

Recently, chemical techniques e.g. photo-etching techniques, have been used in the manufacture of conventional vibrators such as disclosed in Japanese Patent Publication No. 48-3575.

Another recent development is the supporting of vibrators directly by way of portions thereof which do not vibrate with the remainder of the vibrators.

According to one aspect of the present invention there is provided a flexural quartz crystal vibrator made from a laminar plate of quartz crystal material, the vibrator being in the shape of a tuning fork and being provided on at least one face with electrodes by means of which an electric field may be applied to the quartz crystal material of the vibrator, the or each said face being parallel to the plane of vibration of the vibrator, two electrodes on one tine and one electrode on the other tine being electrically connected, and one electrode on said one tine and two electrodes on said other tine being electrically connected.

Preferably said plate is 0.5 millimetres or less in thickness.

Said vibrator may be formed from said plate by a photo-etching technique.

In one embodiment the quartz crystal vibrator is secured directly to a mounting structure *via* a portion thereof which does not vibrate with the remainder of the vibrator.

Preferably the laminar plate is obtained by firstly rotating an X-cut plate about the X-axis through an angle between 0° to 10° and by secondly rotating the X-cut plate about an imaginary axis, generated by the Y-axis as a result of the first rotation, through an angle between 70° and 90°.

According to a further aspect of the present invention there is provided a timepiece including a quartz crystal vibrator as recited above.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:—

Figure 1 is a perspective view of a conventional quartz crystal vibrator of the tuning fork type;

Figure 2 is a cross-section of the vibrator of Figure 1 taken on the line 2—2;

Figure 3 is a perspective view of another type of conventional quartz crystal vibrator of the tuning fork type;

Figure 4 is a cross-section of the vibrator of Figure 3 taken on the line 4—4;

Figure 5, consisting of Figures 5(a) and 5(b), is a perspective view of one embodiment of a quartz crystal vibrator according to the present invention;

Figure 6 is a cross-section of the vibrator of Figure 5 taken on the line 6—6;

Figure 7 is a perspective view of the vibrator of Figure 5 illustrating the mounting thereof;

Figure 8 shows the vibrator of Figure 5 connected to form a vibrator of the three terminal type;

Figures 9-1, 9-2 and 9-3 illustrate one chemical technique for manufacturing a quartz crystal vibrator according to the present invention;

Figure 10, consisting of Figures 10(a) and 10(b), shows in perspective another embodi-

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ment of a quartz crystal vibrator according to the present invention; and

Figure 11 is a cross-section of the vibrator of Figure 10, taken on the line 11—11.

5 Figure 1 is a perspective view of a conventional quartz crystal vibrator of the tuning fork type generally designated by the reference numeral 1. Figure 2 is a cross-section of the vibrator 1 taken on the line 2—2. The
10 vibrator has two electrodes 2, 3 which are provided on all the faces thereof except the end faces. The electrical, mechanical and optical axes of the quartz crystal material of the vibrator are indicated by the axes X, Y, Z respectively. In Figure 2 an angle α
15 shown in Figure 1 is 0° for the sake of simplicity. The supporting wire 4 is electrically connected to the electrode 2 and a supporting wire 5 is electrically connected to the electrode 3, these connections being by
20 soldering or the like.

The vibrator is formed from a plate obtained by rotating a Z-cut plate about the X-axis through an angle α , the angle
25 α being between 0° and 10° and usually about 5° . If a positive voltage is applied to the electrode 3 and a negative voltage is applied to the electrode 2, the electric fields shown by the arrows in Figure 2 are produced. The components of the electric fields
30 in the direction of the X-axis cause the quartz crystal material of the vibrator to become strained. Considering one of the tines of the vibrator, the component of the electric fields in the direction of the X-axis to the left (as
35 seen in Figure 2) of the axis of the tine is in the opposite direction to the component of the electric fields in the direction of the X-axis to the right (again as seen in Figure 2) of the axis of the tine. Thus one side of the
40 tine is in tension and the other side of the tine is in compression. Thus symmetrical flexural vibrations of the vibrator 1 will result when an alternating current is applied
45 between the electrodes 2, 3.

The advantage of a vibrator of this type is that it can be easily connected to an oscillating circuit (not shown) because its dynamic impedance is low and that it can contribute
50 to high precision time keeping when it is used in a wrist watch because the flexion point temperature of the temperature-resonance frequency characteristics is near to room temperature. On the other hand, a
55 vibrator of this type has the following disadvantage. As clearly shown in Figure 1, the electrodes must be provided on all except the end faces and these electrodes are of a complex shape making manufacture difficult and
60 making it impossible to reduce the thickness of the vibrator in the direction of Z-axis below 0.5 millimetres. As a result, when a flat plate of quartz crystal material is to be formed into the shape of a tuning fork this
65 must be done using a diamond wheel cutter

or a supersonic or ultrasonic technique and a photo-etching technique for example employing hydrofluoric acid, cannot be used. The techniques that can be used to form this type of conventional vibrator impose limits
70 upon its miniaturisation.

Furthermore, a vibrator of this type is supported by the supporting wires 4, 5 which must be soldered to relatively narrow portions of the electrodes 2, 3 and the further
75 complicates manufacture.

Figure 3 is a perspective view of an NT-cut conventional quartz crystal vibrator of the tuning fork type formed by a conventional chemical technique. Figure 4 is a cross-section of the vibrator of Figure 3 taken on the line 4—4 of Figure 3. In Figure 4 the thickness of the vibrator has been exaggerated relative to its width and an angle α
80 shown in Figure 3 is set at 0° for the sake of simplicity.

A pair of spaced apart electrodes 7, 8 are disposed on one face of the vibrator 6, a single electrode 9 (Figure 4) being disposed on the opposite face of the vibrator. The
90 electrical, mechanical and optical axes of the quartz crystal material of the vibrator are indicated by the axes X, Y, Z respectively. The vibrator 6 is formed from a plate obtained by rotating an X-cut plate of quartz
95 material through an angle α to the X-axis and then through an angle β to the Y'-axis which is an imaginary Y-axis generated by the rotation through the angle α . The angle α is usually between 0° and 10° and the angle β is usually between 50° and 70° or between -50° and -70° (i.e. between 290° and 310°). As is shown clearly in Figures
100 3 and 4 a vibrator of this type only has electrodes on opposite faces and so it can be formed from a relatively thin plate of quartz crystal material. Accordingly, a vibrator of this type has the advantage that it can be formed by a chemical technique e.g. a photo-etching technique resulting in a
105 relatively small sized vibrator and in particular a relatively thin vibrator which can be mass-produced.

The vibrator 6, however, cannot be supported in the same manner as the vibrator
115 of Figures 1 and 2. The vibrator of Figures 3 and 4 is supported on a mounting structure 10, e.g. a mounting block, by way of a base portion thereof which portion does not vibrate with the remainder of the vibrator. To this end a base portion of the electrode
120 9 is adhered to the mounting structure 10 directly with an alloy having a low melting point or a conductive adhesive agent. Thus the whole size of the vibrator of Figures 3 and 4 can be reduced and its manufacture made easier compared to the vibrator of
125 Figures 1 and 2. The electrodes 7, 8 are electrically connected to respective terminals 13, 14 by lead wires 11, 12 respectively. This
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connection may be effected by a wire bonding technique. The electrode 9 is electrically connected to external circuitry (not shown) via the mounting structure 10. Thus the vibrator is of the three terminal type.

As mentioned above, the vibrator of Figures 3 and 4 has the advantage that it can be made of relatively small size, mass produced and manufactured readily because it is produced by a chemical technique and supported directly on the mounting structure 10. On the other hand a vibrator of this type has the following disadvantages. If positive and negative voltages are applied to the electrodes 8, 9 respectively, the electric fields indicated by the reference numeral 15 in Figure 4 are produced within the quartz crystal material. A component 16 of the electric field 15 in the direction of the X-axis causes strain of the quartz crystal material. An alternating current applied to the electrodes 8, 9 will cause the vibrator to perform symmetrical flexural vibrations for the same reasons as described with reference to Figures 2. The component 16, however, is extremely small compared to the electric field 15 since the former is related to the latter by the cosine of the angle β . Consequently, the vibrator has a relatively high dynamic impedance. This dynamic impedance has been found theoretically and practically to be inversely proportional to $\cos^2 \beta$. When β is 70° the dynamic impedance increases 8.5 times compared to the case where β equals 0° . When β equals 75° the dynamic impedance increases 15 times compared to the case where β equals 0° and when β equals 90° the dynamic impedance is infinity. As the flexion point temperature of the temperature-resonance frequency characteristics increases with increase in the angle β , the point of zero temperature coefficient is relatively low because the angle β is generally 70° since otherwise the dynamic impedance would become unacceptably high. Thus a vibrator of this type is unsuitable for timepieces because its dynamic impedance is too high and the flexion point temperature is too low even though the vibrator is advantageous from the point of view of size and the fact that it may be mass produced.

As mentioned above in detail, the conventional vibrator of Figures 1 and 2 has the advantage that its dynamic impedance is relatively low and its flexion point temperature is relatively high but the disadvantage that it is difficult to miniaturise, especially to make thin, it cannot be made by a chemical technique and the use of supporting wires causes problems. On the other hand the conventional vibrator of Figures 3 and 4 has the advantage that it can be made relatively thin, that it can be made by a chemical technique and that it can be bonded directly to the mounting structure, but the disadvantage that

its dynamic impedance is relatively high and its flexion point temperature is relatively low. Conventionally, the two types of vibrator were considered to be different since the methods of applying the electric fields are dissimilar. But in view of the similarity of the angles α and β , the two types of vibrator may be regarded as one. That is to say, the angle α for both types of vibrator is between 0° and 10° and for the conventional vibrator of the type illustrated in Figures 1 and 2 the angle β is 90° whereas the angle β for a conventional vibrator of the type illustrated in Figures 3 and 4 is between 50° and 70° or between -50° and -70° .

The following embodiments of the present invention have the advantages of the conventional vibrator as described above without their disadvantages.

Figure 5, consisting of Figures 5(a) and 5(b), is a perspective view of one embodiment of a quartz crystal vibrator 17 according to the present invention, Figure 5(a) being a front view thereof and Figure 5(b) being a rear view thereof. In Figure 6, an angle α shown in Figure 5(a) is set at 0° for the sake of simplicity. Electrodes 18, 19 are provided on one face of the vibrator and electrodes 20, 21 are provided on the opposite face. Enlarged portions 22, 23 of the electrodes 20, 21 respectively are provided for securing or assisting in securing the vibrator to a mounting structure 27 (Figure 7). Connecting wires 24, 25 electrically interconnect the electrodes 18, 20 and the electrodes 19, 21 respectively to form a vibrator of the two terminal type.

A thin metallic film 26 is provided on the end of each tine of the vibrator to enable the resonant frequency from the vibrator to be adjusted. To this end the films 26 are irradiated with a laser beam to evaporate some of the metal thereof until the desired resonance frequency is achieved. The films 26 are spaced from the electrodes in this embodiment but it is not impossible to connect them to electrodes 18, 19.

The electrical, mechanical and optical axes of the quartz crystal material of the vibrator are indicated by the axes X, Y, Z respectively. The vibrator is formed from a plate obtained by rotating an X-cut plate about the X-axis through an angle α and further rotating it through an angle γ about the Y'-axis which is an imaginary Y-axis generated by the Y-axis through rotation of the angle α . Z' is an imaginary Z-axis generated by rotation through the angle α . The angle α is between 0° and 10° and the angle γ is between 70° and 90° or between -70° and -90° (i.e. 290° to 270°) in which range advantageous temperature-resonance frequency characteristics are obtained.

If positive and negative voltages are applied to the lead wires 24, 25 the electric field shown by the curved arrows in Figure 6 are

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produced in the quartz crystal material. Thus strains are produced in each of the tines of the vibrator and if an alternating current is applied between the electrodes, the vibrator will perform symmetrical flexural vibrations. As it is the components of the electric fields in the direction of the X-axis which contribute to vibration of the vibrator and as these components are greater than in the conventional vibrator of Figures 4 and 5, the vibrator of Figure 6 has a lower dynamic impedance than the vibrator of Figures 4 and 5. Furthermore, since electrodes are not provided on all opposed surfaces of the tines, the vibrator may have a thickness of 0.5 millimetres or less in the direction of the Z-axis. Therefore, a chemical technique, e.g. a photo-etching technique can be used in the manufacture of the vibrator of Figure 5 and consequently the size and thickness of the vibrator can be reduced and its mass production enhanced.

Figures 9-1, 9-2 and 9-3 illustrate one chemical technique for manufacturing a quartz crystal vibrator according to the present invention. In Figure 9-1 a thin quartz crystal plate 33 which is 0.5 millimetres or less in thickness and whose faces have been ground to a mirror finish is photo-etched to form a plurality of tuning forks 33¹ simultaneously. Figures 9-2 and 9-3 illustrate a photo-etching technique used to shape the electrodes and the tuning fork: Figures 9-2 and 9-3 being sectional views on the line A-A¹ of Figure 9-1. In Figure 9-2, a photo-resist 35 in the shape of the electrodes to be formed by the photo-etching technique is deposited on one surface of a thin metallic film 34 which is deposited or coated on each face of the plate 33. The parts 36 of each film 34 not covered with the photo-resist are removed by using an acid such as hydrochloric acid.

Thus, the electrodes are first formed on the plate 33. Next, as shown in Figure 9-3, a photo-resist 37 in the shape of a tuning fork of the vibrator to be formed by the photo-etching technique is deposited on the plate 33. The parts 38 of the plate 33 not covered with the photo-resist are then removed using hydrogen fluoride or hydrofluoric acid or the like.

By using such a technique an ultra-small-sized vibrator can be produced and such a vibrator can be mounted in the manner illustrated in Figure 7 or Figure 3.

Figure 7 illustrates the mounting of the vibrator 17 shown in Figures 5 and 6. The mounting structure 27 is C-shaped in cross-section and is made of non-conductive material such as a ceramic. Conductors 28, 29 are provided on the mounting structure which insulates the conductors from one another. The vibrator 17 is securely adhered to the conductors 28, 29 with a low melting

point alloy, a conductive adhesive agent or the like in such a way that the electrode 22 of the vibrator is electrically connected to the conductor 28, and the electrode 23 and the conductor 29 are electrically connected. Therefore, the electrode 18 is connected to the conductor 28 via the connecting wire 24 and the electrode 20, and similarly, the electrode 19 is connected to the conductor 29 via the connecting wire 25 and the electrode 21. Thus a vibrator of the two terminal type is formed. Lead wires 30, 31 are provided to connect the conductors 28, 29 to external circuitry (not shown). The connecting wires 24, 25 need not necessarily be of wire: they may be made of a low melting point alloy or a conductive adhesive agent or the like. In place of the connecting wires 24, 25, connecting electrodes may be provided on the side surfaces of the vibrator as shown by a dotted line 32.

Though the vibrator of Figure 5 is shown as being of the two terminal type, the electrodes thereof may be connected so that the vibrator is of the three-terminal type. To this end, the electrodes 19, 21 are connected as a common electrode, the electrode 2 is connected as a driving electrode and the electrode 18 is connected as a detecting electrode. This arrangement is shown in Figure 8.

Figure 10, consisting of Figures 10(a) and 10(b) illustrates another embodiment of a quartz crystal vibrator 39 according to the present invention, Figure 10(a) being a front view thereof and Figure 10(b) being a rear view thereof. Figure 11 is a cross-section of the vibrator of Figure 10.

The vibrator 39 is formed from a plate of quartz crystal material in a similar manner to the vibrator of Figure 5. Electrodes 41, 42, 43, 44 are provided on one face of the vibrator and electrodes 45, 46 on the opposite face. Enlarged portions 47, 48 of the electrodes 45, 46 are provided for securing or assisting in securing the vibrator directly to a mounting structure (not shown). A thin metallic film 49 is provided on the end of each tine of the vibrator to enable the resonant frequency of the vibrator to be adjusted as described in connection with Figure 5.

In this vibrator a one-input and a one-output filter can be constructed by electrically connecting the electrodes 41, 44, electrically connecting the electrodes 42, 43 as a pair of detecting electrodes, and electrically connecting the electrodes 45, 46 as a pair of driving electrodes.

Alternatively a one-input and a two-output filter can be constructed by electrically connecting the electrodes 45, 46 as a pair of driving electrodes, electrically connecting the electrodes 41, 42 as one pair of detecting electrodes and electrically connecting the

electrodes 43, 44 as the other pair of detecting electrodes.

The present invention can be applied to a free-free-bar flexural quartz crystal vibrator or any other type of flexural quartz crystal vibrator.

Quartz crystal vibrators similar to those described above are also described and claimed in the following co-pending Applications filed with the present Application:

Application No. 16169/74

(Serial No. 1,460,636),

Application No. 16170/74

(Serial No. 1,460,638),

Application No. 16201/74

(Serial No. 1,460,637), and

Application No. 16202/74

(Serial No. 1,460,639).

The disclosures of these Applications are incorporated herein by way of reference.

Quartz crystal vibrators according to the present invention may, if desired, be made from a plate of quartz crystal material in a similar manner to that described in connection with the conventional vibrator of Figures 3 and 4.

WHAT WE CLAIM IS:—

1. A flexural quartz crystal vibrator made from a laminar plate of quartz crystal material, the vibrator being in the shape of a tuning fork and being provided on at least one face with electrodes by means of which an electric field may be applied to the quartz crystal material of the vibrator, the or each said face being parallel to the plane of vibration of the vibrator, two electrodes on one

tine and one electrode on the other tine being electrically connected, and one electrode on said one tine and two electrodes on said other tine being electrically connected.

2. A quartz crystal vibrator as claimed in claim 1 in which said plate is 0.5 millimetres or less in thickness.

3. A quartz crystal vibrator as claimed in claim 1 or 2 in which said vibrator is formed from said plate by a photo-etching technique.

4. A quartz crystal vibrator as claimed in any preceding claim secured directly to a mounting structure *via* a portion thereof which does not vibrate with the remainder of the vibrator.

5. A quartz crystal vibrator as claimed in any preceding claim in which said laminar plate is obtained by firstly rotating an X-cut plate about the X-axis through an angle between 0° to 10° and by secondly rotating the X-cut plate about an imaginary axis, generated by the Y-axis as a result of the first rotation, through an angle between 70° and 90°.

6. A quartz crystal vibrator as claimed in claim 1 and substantially as herein described with reference to and as shown in Figures 5 to 11 of the accompanying drawings.

7. A timepiece including a quartz crystal vibrator as claimed in any preceding claim.

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electrodes 43, 44 as the other pair of detecting electrodes.

The present invention can be applied to a free-free-bar flexural quartz crystal vibrator or any other type of flexural quartz crystal vibrator.

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WHAT WE CLAIM IS:—

1. A flexural quartz crystal vibrator made from a laminar plate of quartz crystal material, the vibrator being in the shape of a tuning fork and being provided on at least one face with electrodes by means of which an electric field may be applied to the quartz crystal material of the vibrator, the or each said face being parallel to the plane of vibration of the vibrator, two electrodes on one

tine and one electrode on the other tine being electrically connected, and one electrode on said one tine and two electrodes on said other tine being electrically connected.

2. A quartz crystal vibrator as claimed in claim 1 in which said plate is 0.5 millimetres or less in thickness.

3. A quartz crystal vibrator as claimed in claim 1 or 2 in which said vibrator is formed from said plate by a photo-etching technique.

4. A quartz crystal vibrator as claimed in any preceding claim secured directly to a mounting structure *via* a portion thereof which does not vibrate with the remainder of the vibrator.

5. A quartz crystal vibrator as claimed in any preceding claim in which said laminar plate is obtained by firstly rotating an X-cut plate about the X-axis through an angle between 0° to 10° and by secondly rotating the X-cut plate about an imaginary axis, generated by the Y-axis as a result of the first rotation, through an angle between 70° and 90°.

6. A quartz crystal vibrator as claimed in claim 1 and substantially as herein described with reference to and as shown in Figures 5 to 11 of the accompanying drawings.

7. A timepiece including a quartz crystal vibrator as claimed in any preceding claim.

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