

PATENT SPECIFICATION (11)

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(54) QUARTZ CRYSTAL VIBRATOR

(71) We, KABUSHIKI KAISHA SUWA SEIKOSHA, a Japanese Company of Japan 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.

In recent years, the development of a small sized vibrator has advanced and there are a large number of proposals for wrist-watches using quartz crystal vibrators to produce a time standard. One proposal relates to a tuning fork type quartz crystal vibrator, made by a photo-etching technique. Such a vibrator has a relatively low frequency of vibration and an extremely small size and thus is particularly suitable for use in a wristwatch.

According to the present invention there is provided a quartz crystal vibrator mounted on a support structure so that a substantially planar interface is formed therebetween, the coefficients of thermal expansion of the support structure in all directions in the plane of the interface being substantially the same as the coefficients of thermal expansion of at least that portion of the vibrator to which the support structure is attached in the plane of the interface.

Preferably the support structure is made of electrically insulating material. Said insulating material may be quartz crystal material.

In a preferred embodiment the vibrator includes electrode means on one surface of the vibrator and electrically conductive means on the support structure, the vibrator being bonded to the support structure so that the electrode means are in electrical contact with the electrically conductive means. The electrode means may comprise a pair of spaced apart electrodes and said electrically conductive means comprise a pair of spaced apart metallic films on a surface of the support structure which is bonded to the vibrator so that the elec-

trodes are bonded to the respective metallic films.

The vibrator may be of the tuning fork type.

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

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

Figure 2 is a perspective view of a rear face of the vibrator of Figure 1;

Figure 3 illustrates the crystallographic relationship between the vibrator of Figure 1 and an NT-cut quartz crystal plate from which the vibrator is made;

Figure 4 is a schematic view illustrating the mode of operation of the vibrator of Figure 1;

Figure 5 is a perspective view of another tuning fork type quartz crystal vibrator;

Figure 6 is a perspective view of a rear face of the vibrator of Figure 5;

Figure 7 is similar to Figure 3 illustrating the crystallographic relationship of the vibrator of Figure 5;

Figure 8 is a schematic view illustrating the mode of operation of the vibrator of Figure 5;

Figures 9 and 10 illustrate a disadvantage of the vibrator of Figure 5; and

Figure 11 is a perspective view of a tuning fork type quartz crystal vibrator according to the present invention.

In the drawings, like parts have been designed by the same reference numerals.

Referring first to Figure 1 there is illustrated a tuning fork type quartz crystal vibrator 1 known in Japan. The vibrator 1 is formed from an NT-cut quartz crystal plate, which is several tens of microns in thickness, using a photo-etching technique. Electrodes 2, 3 on a front face (Figure 1) of the vibrator are connected to respective terminals 6, 7 by bonding wires 4, 5. An electrode 9 is provided on a rear face (Figure 2) of the vibrator 1. The vibrator 1 is bonded to a support member 8 which also serves as a terminal block which is in electrical connection with a portion 10 of 100

the electrode 9. The support member 8 is fixed to the vibrator 1 by means of solder or an eutectic mixture of gold or silver which is used as an adhesive.

Figure 3 illustrates the relationship between the crystallographic axes X, Y, Z of the NT-cut quartz crystal plate and the physical axes X^1 , Y^1 , Z^1 of the vibrator 1, an angle α being a first rotation or angle, i.e. the angle between axes Y, Y^1 and an angle β being a second rotational angle, i.e. the angle between the axes X^1 , Z. The angle α is a predetermined angle between 0° and 10° and the angle β is a predetermined angle between 50° and 70° . When an electric voltage is applied to the electrodes 2, 3, 9 electric fields 11, 12 (shown in Figure 4) are set up in each time of the vibrator and so the vibrator begins to vibrate. In Figure 4, the angle α is set at 0 for simplicity of illustration.

The conventional vibrator described above may be made of extremely small size and may be produced relatively easily. However, it is only the component 13, 14 in the direction of the X-axis of the respective electric fields 11, 12 that cause the vibrator to vibrate. Accordingly, the larger the angle β , the greater the dynamic impedance of the vibrator, since the dynamic impedance is inversely proportional to $\cos^2 \beta$. Further, the temperature at which there is a zero temperature coefficient depends upon the angle β and is 20°C when β is 75°C which results in a dynamic impedance of 1 megohm or more. Accordingly, it is necessary to make the angle $\beta > 75^\circ$ if there is to be a zero temperature coefficient of 25°C but this means that the vibrator has a dynamic impedance of several megohms. It is desirable that the vibrator has a zero temperature coefficient at 25°C if it is to be employed in a wristwatch. Therefore, there are several practical limitations in using the tuning fork type quartz crystal vibrator of Figure 1 in an electronic wristwatch.

Figure 5 is a perspective view of another tuning fork type quartz crystal vibrator 15. The vibrator 15 is formed from a quartz crystal plate by a photo-etching technique so that an angle γ (Figure 7 which corresponds to Figure 3) is predetermined and is between 0° and 10° .

Electrodes 16, 17 are formed on a front face (Figure 5) of the vibrator and electrodes 25, 26 are formed on a rear face (Figure 6). An electric field is applied by means of the electrodes 16, 17, 25, 26 to the vibrator as will be explained in greater detail hereinafter. The vibrator 15 is bonded to two metallic films 18, 19 on a support structure 24 by way of portions 27, 28 of the electrodes 25, 26 respectively. The support structure 24 is made of an electrically insulating material and the

metallic films 18, 19 are formed thereon by a depositing technique or a sintering technique. The electrodes 16, 25 are connected together and to an electrode terminal 22 by a bonding wire 20, and the electrodes 17, 26 are connected together to an electrode terminal 23 by a bonding wire 21.

As shown in Figure 8, when an electric field is applied to the vibrator stresses, indicated by arrows, are generated and these are in a direction substantially parallel to the X-axis. Consequently, the dynamic impedance of the vibrator 15 is in the region of 15 kilohms which dynamic impedance is considerably less than the dynamic impedance of the vibrator shown in Figure 1. The vibrator may have a zero temperature coefficient at any temperature in the range between 20°C and 40°C .

Accordingly, due to its increased efficiency and its small size, the vibrator, shown in Figure 5, is suitable for use in a timepiece, e.g. an electronic wristwatch. However, if the support structure 24 is made of a material which has a relatively low coefficient of thermal expansion, such as glass or ceramic material, a break, such as that shown at 29 in Figure 9, may occur. This break is caused because the vibrator itself has a relatively large coefficient of thermal expansion since it is made of quartz crystal material and the support structure 24 has a relatively low coefficient of thermal expansion, and stresses are built up as a result of cooling from the temperature at which the vibrator is bonded to the support structure. The tensile stress so generated in the vibrator 15 is shown by an arrow 30 in Figure 10. For example, if a support structure is made of a ceramic material having a coefficient of thermal expansion of $7 \times 10^{-6}/^\circ\text{C}$. and the vibrator is bonded to the support structure using an eutectic mixture of Au/su, a tensile stress of about 25 kg/mm² is generated and this is greater than the breaking stress of a quartz crystal plate several tens of microns in thickness from which the vibrator is made. In Figure 10 the reference numeral 13 indicates the bonding material between the support structure 24 and the vibrator 15.

In the conventional vibrator of Figure 1, metals, such as, for example, nickel or brass, are used for the support structure 8 and these materials have a coefficient of thermal expansion nearly equal to or a little higher than that of the quartz crystal material. In this case, breaks in the vibrator are avoided because the quartz crystal material is stronger in compression than in tension. However, if there is a relatively large compressive stress generated in the vibrator, the ageing characteristics of the vibrator are relatively poor and there will be a frequency

shift if the vibrator is subjected to a shock, e.g. if it is dropped.

Figure 11 shows a quartz crystal vibrator according to the present invention which does not suffer from the aforementioned difficulties. The vibrator 15 is mounted on a support structure 24 so that a substantially planar interface is formed therebetween. A break in the vibrator is avoided by using, for the support structure 32, electrically insulating materials whose coefficients of thermal expansion in the plane of the interface are substantially equal to the coefficients of thermal expansion of the vibrator in the same plane. Apart from this the support structure 32 is of similar construction to the support structure 24. As the coefficient of thermal expansion in the lengthwise direction of the vibrator is different from that in a direction at right angles thereto, a piece of quartz crystal material, which is cut in the same direction as the vibrator, is most suitable as the material for the support structure 32.

The tuning fork type quartz crystal vibrator according to the present invention and described above is thin, has a relatively good efficiency, is extremely small and may be mass produced readily and cheaply using photo-etching techniques.

WHAT WE CLAIM IS:—

1. A quartz crystal vibrator mounted on a support structure so that a substantially planar interface is formed therebetween, the coefficients of thermal expansion of the support structure in all directions in the plane of the interface being substantially the same as the coefficients of

thermal expansion of at least that portion of the vibrator to which the support structure is attached in the plane of the interface.

2. A vibrator as claimed in claim 1 in which the support structure is made of electrically insulating material.

3. A vibrator as claimed in claim 2 in which said insulating material is quartz crystal material.

4. A vibrator as claimed in any preceding claim including electrode means on one surface of the vibrator and electrically conductive means on the support structure, the vibrator being bonded to the support structure so that the electrode means are in electrical contact with the electrically conductive means.

5. A vibrator as claimed in claim 4 in which said electrode means comprises a pair of spaced apart electrodes and said electrically conductive means comprise a pair of spaced apart metallic films on a surface of the support structure which is bonded to the vibrator so that the electrodes are bonded to the respective metallic films.

6. A vibrator as claimed in any preceding claim in which the vibrator is of the tuning fork type.

7. A quartz crystal vibrator substantially as herein described with reference to and as shown in Figure 11 of the accompanying drawings.

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