

"PIEZO-ELECTRIC VIBRATOR ASSEMBLY"

This invention relates to a piezo-electric vibrator assembly and, although the invention is not so restricted, it relates more particularly to an ultra-small piezo-electric vibrator assembly whose vibrator comprises a main vibrating portion which vibrates longitudinally and which is formed integrally with a tuning fork type supporting member by a photo-lithographic process.

According to the present invention, there is provided a piezo-electric vibrator assembly comprising a sealed receptacle within which is mounted a piezo-electric vibrator of the longitudinal vibration type, the vibrator having a main vibrating portion which vibrates longitudinally and which is provided with main electrodes, a supporting member which supports the main vibrating portion adjacent the point where the vibrating displacement of the latter is smallest, the supporting member having a tuning fork portion whose arms are disposed on opposite sides of a part of the main vibrating portion and whose base is provided with base terminals which are respectively electrically connected to the main electrodes, the resonant frequency of the main vibrating portion being substantially the same as that of the second harmonic of the resonant frequency of the supporting member, and a terminal member which is hermetically sealed to one end of the receptacle and through which extend conductive leads which are electrically connected

to the base terminals by means extending over a cross-sectional area greater than that of the conductive leads.

5 In its preferred form, the assembly of the present invention employs an ultra-small piezo-electric vibrator of the longitudinal vibration type whose frequency is in the range of several 100kHz to several MHz and which may be produced at a low manufacturing cost.

10 Preferably, the supporting member also has a connecting portion which extends between the ends of the arms remote from said base and the said point.

The arms are preferably parallel to the main vibrating portion.

15 Preferably, the main vibrating portion and the supporting member are integral with each other.

The conductive leads may be rod or plate-shaped, and the terminal member may be a press fit in the receptacle.

20 Metal films may be provided on side surfaces at an end portion of the main vibrating portion for adjusting the frequency of the vibrator.

Film electrodes of the same polarity may be provided on corresponding side surfaces at an end portion of the main

vibrating portion.

A recess may be provided at a part of the main vibrating portion or of the said base where a main electrode or a conductive lead has been split to form a pair thereof.

5 The vibrator may have been made by a photo-lithographic process comprising forming a piezo-electric wafer into the shape of a vibrator, depositing a conductive thin film over substantially the whole surface of said wafer, forming a photo-resist on said conductive thin film into the shape of
10 electrodes, etching said conductive thin film to form said electrodes by utilising said photo-resist as a protective film, and removing said photo-resist.

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

15 Figure 1 is a perspective view of a piezo-electric vibrator of the longitudinal vibration type which is not in accordance with the present invention,

 Figures 2(A) to 2(E) are exploded perspective views showing a piezoelectric vibrator assembly incorporating the
20 structure of Figure 1;

 Figure 2' is a plan view of the vibrator of Figures 2(A) to 2(E);

 Figure 3 illustrates a vibrator assembly in which the vibrator of Figure 2 is sealed in a receptacle, Figures
25 3(A) to 3(C) being respectively a top plan view, a sectional

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view and a bottom plan view thereof;

Figures 4, and 17(A) to 17(C) are a perspective view, a plan view, a sectional view and a side view respectively of an embodiment of a piezo-electric vibrator assembly in accordance with the present invention;

Figure 5 shows the vibration displacement of a part of the supporting member of the vibrator which forms part of the assembly of Figure 4;

Figure 6 is a diagram illustrating the secondary high harmonics of the vibration of the supporting arms of the said vibrator;

Figures 7 to 10 illustrate a frequency adjusting portion of a main vibrating portion of the said vibrator;

Figures 11 to 13 illustrate a process for forming electrodes;

Figures 14 to 16 illustrate the concave structure which is a feature of this invention.

Terms such as "upper" and "lower", as used in the description below, are to be understood to refer to directions as seen in the accompanying drawings.

Figure 1 is a perspective view of a vibrator assembly comprising a piezo-electric vibrator of the longitudinal vibration type in which a main vibrating portion of the vibrator, which vibrates longitudinally, and a tuning fork type supporting member are integrally formed by a photo-lithographic process, this vibrator being as shown in Laid Open Japanese Patent

Application No. 57/138212. The vibrator of Figure 1 comprises a main vibrating portion 1, supporting arms 3a, 3b, a connecting portion 2a, 2b for connecting the supporting arms 3a, 3b generally to the centre of the main vibrating portion 1, and a supporting base 4, the vibrator being integrally formed from a quartz crystal plate by a photo-lithographic process such as a photo-etching process. The connecting portion 2a, 2b, the supporting arms 3a, 3b and the supporting base 4 as a whole will be referred to as a supporting member

5. The quartz crystal plate is cut in the vertical direction with respect to its optical or Z axis. The main vibrating portion 1 is obtained parallel to the mechanical or Y axis of the quartz crystal. Main electrodes 1'a, 1'b are respectively plated on opposite side surfaces of the main vibrating portion 1, and external electrodes 5'a, 5'b are connected through the connecting portion 2a, 2b. A vibrator as shown in Figure 1 may be used to provide a frequency of 1MHz and the main vibrating portion 1 of the vibrator may have a length L equal to 2.75mm, a width W equal to 0.1mm and a thickness T equal to 0.2mm. Thus the thickness T of the main vibrating portion 1 is larger than the width W thereof. The supporting base 4 is mounted on a mounting base 6 and the whole is hermetically sealed in a receptacle (not shown in Figure 1).

A vibrator assembly as shown in Figure 1 has the advantage

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that the vibrating characteristics are excellent because the main electrodes 1'a, 1'b produce an electric field in the direction parallel to the electric or X axis of the quartz crystal and because the main vibrating member 1 is supported by the supporting member 5 which is shaped like a tuning fork.

However, the construction shown in Figure 1 has some defects. In general, a piezo-electric vibrator of the longitudinal vibration type has the characteristic that expansion and contraction of the main vibrating portion 1 in the direction of the longer side thereof causes expansion and contraction in the direction of the shorter side thereof. So, as in Figure 1, if the supporting member 5 is mounted directly on the mounting base 6 of a rigid body such as a ceramic body, vibration of the supporting member 5 caused by expansion and contraction of the main vibrating portion 1 in the direction of the shorter side thereof is directly transmitted to the receptacle of the assembly (not shown in the drawing). Consequently, the excellent vibration characteristics of the vibrator of Figure 1 are impaired.

Moreover, in order to allow the vibrator to vibrate without being affected by external shocks to the receptacle, the weight of the receptacle should be sufficiently large with respect to that of the vibrator. This causes it to be difficult to make the assembly small.

Furthermore, since the supporting base 4 of the supporting

member 5 contacts the mounting base 6 over a large area and the whole assembly is hermetically sealed, the main vibration which is produced by the main vibrating portion 1 is hindered, so that the vibration efficiency is impaired.

5 Reference is now made to Figures 2 and 3 wherein there is illustrated a longitudinal vibrator unit incorporating the vibrator shown in Figure 1.

 Figures 2A to 2E are perspective views of individual parts of this longitudinal vibrator unit showing an upper
10 lid 13, a frame 12, a vibrator 7, a mounting member 8 (corresponding to the whole of the mounting base 6 in Figure 1) and a lower lid 9, respectively. Figure 2' is a plan view of the vibrating portion. As is particularly illustrated in Figure 2C, the supporting base 4 of the vibrator 7 is mounted
15 on the mounting member 8 by means of Pb/Sn solder or other organic adhesives. The interior 10 of the supporting member 8 provides space for the vibrator to vibrate.

 In the structure of Figure 2, the main electrodes 1'a, 1'b are connected to external electrodes 8'a, 8'b provided
20 on the mounting member 8 through the electrodes plated on the supporting base 4. The external electrodes 8'a, 8'b are connected (by means not shown) to another pair of external electrodes 9'a, 9'b plated on the lower lid 9 through recesses 11a, 11b provided on the mounting member 8. Thus, the main
25 electrodes 1'a, 1'b of the vibrator 7 are electrically connected

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to the external electrodes 9'a, 9'b. After joining together the mounting member 8 and the lower lid 9, the configuration of the external electrodes 9'a, 9'b cannot be seen at all from the outside. Also, as shown in Figure 2', at opposite ends of the main vibrating portion 1 there are electrodes 1'c, 1'd for adjusting the frequency of the vibrator. The electrodes 1'c, 1'd are plated on the planar end surfaces of the main vibrating portion 1.

Hermetical sealing of the vibrator is completed by mounting the frame 12 on the mounting member 8 and by plating the upper lid 13 on the frame 12.

Figures 3A, 3B, 3C illustrate the completed vibrator assembly of Figure 2, Figures 3A, 3B and 3C being a top plan view, a sectional view and a bottom plan view respectively. In the completed vibrator assembly shown in Figure 3, the assembly has a length A equal to 8.33mm (0.33 inch), a width B equal to 3.94mm (0.155 inch), and a thickness C equal to 1.52mm (0.08 inch).

Thus, as mentioned before, the miniaturization of the vibrator assembly of Figures 2 and 3 is less than completely satisfactory.

Furthermore, manufacturing an assembly as described above in which the mounting member 8 and the lower lid 9 are used involves high manufacturing costs because of the large number of parts and the cost of assembling them together.

The object of the present invention is to overcome the above-mentioned disadvantages.

An embodiment of a piezo-electric vibrator assembly in accordance with the present invention will now be described with reference to Figures 4, 17A, 17B and 17C which are a perspective view, a plan view, a sectional view and a side view thereof, respectively.

In Figure 4 there is shown a piezo-electric vibrator 100 of the longitudinal vibration type. The vibrator 100 has a main vibrating portion 14 which vibrates in the longitudinal direction and which is supported by a connecting portion 15a, 15b at the point where the amount of vibrating displacement of the main vibrating portion 14 is smallest (that is, substantially at the centre thereof).

The connecting portion 15a, 15b is symmetrical in the direction of the width of the main vibrating portion 14. The connecting portion 15a, 15b is provided with electrodes 15'a, 15'b. From opposite ends of the connecting portion 15a, 15b, supporting arms 16a, 16b extend parallel to the main vibrating portion 14 in the same direction, which supporting arms 16a, 16b extend to a supporting base 17. The supporting arms 16a, 16b are respectively provided with electrodes 16'a, 16'b. Thus, a supporting member 18 which consists of the connecting portion 15a, 15b, the supporting arms 16a, 16b and the supporting base 17 surrounds one half of the main vibrating portion 14

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and the portion 16a, 16b, 17 thereof is of tuning fork shape. The main vibrating portion 14 and the supporting member 18 are formed integrally by a photo-lithographic process such as a photo-etching process.

5 A pair of main electrodes 14'a, 14'b are respectively plated on the opposite side surfaces of the main vibrating portion 14, and external electrodes 18'a, 18'b are plated on the supporting member 18. The main electrodes 14'a, 14'b and the external electrodes 18'a, 18'b are connected to each other through the connecting portion 15a, 15b. An hermetic terminal 10 19 is provided at the lower end of the supporting member 18. Rod-like or plate-like conductive and resilient lead terminals 20a, 20b are provided parallel to the upper surface of the supporting base 17 so as to extend through the hermetic terminal 15 19. At the portion of the supporting base 17 near to the lower end thereof, base terminals 17'a, 17'b on the upper surface of the supporting base 17 are directly electrically connected to the side surfaces of the lead terminals 20a, 20b which are adjacent to the supporting base 17 by means of Pb/Sn solder or other organic adhesives (not shown) so that the contact area 20 therebetween is larger than the cross-sectional area of the lead terminals 20a, 20b. Finally, the vibrator assembly is hermetically sealed in a cylindrical receptacle 21 shown by broken lines, the terminal 19 being hermetically sealed to 25 one end of the receptacle 21.

Thus the supporting member 18 has a tuning fork portion 16a, 16b, 17 whose arms 16a, 16b are disposed on opposite sides of a part of the main vibrating portion 14 and whose base 17 is provided with the base terminals 17'a, 17'b which are
5 respectively electrically connected to the main electrodes 14'a, 14'b.

As described above, in the piezo-electric vibrator 100 of the longitudinal vibration type which is shown in Figure 4, the supporting base 17 of the vibrator 100 is secured to
10 the resilient lead terminals 20a, 20b. Such a structure has some advantages which are not obtained by the structures shown in Figures 1-3.

In the first place, the electrodes on the vibrator 100 can, in effect, be directly drawn out of the receptacle 21 by
15 securing the vibrator 100 to the conductive lead terminals 20a, 20b. As the vibration produced by the main vibrating portion 14 is sufficiently damped through the resilient lead terminals 20a, 20b, the hermetic terminal 19 and the receptacle 21 can be reduced in weight.

20 Secondly, the contact area between the supporting base 17 and the lead terminals 20a, 20b may be as small as 0.15mm, so that the effect on the vibration of the vibrator 100 of securing the lead terminals 20a, 20b to the vibrator
25 100 is largely reduced. Consequently the vibrating frequency of the vibrator can be controlled so as to be extremely small at the supporting base 17.

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Thirdly, the vibrator 100 is hermetically sealed in a simple cylindrical receptacle 2' into which the hermetic terminal 19 is press fitted. Thus, the number of parts is small and it is easy to seal them together, whereby to reduce manufacturing cost.

In contrast, in the case of the construction shown in Figure 3, six planar surfaces of four members must be elaborately polished so as to achieve perfect bonding between the four members. Accordingly, the manufacturing costs are unnecessarily high because of the number of parts used, the considerable skill required to polish the surfaces of the members and so on. Moreover, the need to bond so many members together necessarily reduces the sealing efficiency.

Moreover, as is well known, in order to reduce the power consumption of vibrator assemblies, the C.I (crystal impedance) value thereof should be kept small. So a sealing vacuum is usually used in the case of sealing a quartz crystal vibrator for producing a low frequency, such as 32kHz. When sealing the vibrator of Figure 3 in a vacuum, many processes are required to be undertaken in a vacuum apparatus, such processes including dissolving the adhesives by heating, then applying pressure on the assembly, and then cooling down the assembly. When sealing the vibrator of Figure 4, however, the sealing is completed only by press fitting the hermetic terminal 19 into the receptacle 21 at normal temperature in a vacuum apparatus. Such a simplified process of sealing as described

above is also an advantage in reducing manufacturing cost.

The piezo-electric vibrator assembly of Figure 4 has a structure such that the vibrator 100 is sealed in a cylindrical receptacle 21 with resilient conductive lead terminals 20a, 20b. The advantages which are derived from such a vibrator assembly can be equally obtained even if the kind of lead terminals or receptacle vary. For example, the conductive lead terminals 20a, 20b may be either rod-like or plate-like. The receptacle 21 may be made of either non-transparent material such as metal or ceramics or transparent material such as glass or quartz crystal. Also, the receptacle 21 need not have a circular cross section but may, for example, be oval in cross-section.

The vibrator assembly of Figure 4 will now be described in greater detail.

The longitudinal vibration of the main vibrating portion 14 causes the connecting portion 15a, 15b and the supporting arms 16a, 16b to vibrate flexionally in the direction of the shorter side of the main vibrating portion 14. The displacement of the connecting portion 15a, 15b and the supporting arms 16a, 16b caused by the flexional vibration is shown in Figure 5 by dotted lines. In order to improve the vibration efficiency of the vibrator, the effect of the flexional vibration of the supporting member 18 on the vibration of the main vibrating portion 14 (hereinafter

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referred to as the main vibration) should be as small as possible. The above requirement is met by generally synchronizing the resonant frequency of the flexional vibration of the supporting member 18 with that of the main vibration.

5 In general, the frequency of the vibrator 100 of the longitudinal vibration type is in the range of some 100kHz to 1MHz, while that of the flexional vibration of the supporting arms 16a, 16b is much smaller, depending on the width and length thereof. In order to synchronize the resonant frequency of the supporting member 18 with that of the main vibrating portion 14, the second harmonic of vibration of the supporting member 18 is utilized, which second harmonic is shown in Figure 6. In Figure 6, 21a indicates the supporting base 17 of the Figure 4 construction and 22a, 22b illustrate the second harmonics of the supporting arms 16a, 16b shown in Figure 5, respectively. As is apparent from Figure 6, the harmonics 22a, 22b are 180° out of phase. The frequency of the second harmonics is about 15 times as great as that of the basic wave of the vibration frequency of the supporting member 18 and thus the frequency f of some 100kHz to 1MHz is easily obtained by utilizing the second harmonics. Consequently the synchronization of the resonant frequencies of the main vibrating portion and the supporting member 18 can be realized.

25 In the construction of Figure 4, since the flexional vibration of the symmetrical supporting arms 16a, 16b is balanced and since the vibration at the supporting base 17 is

small, it is possible to secure the supporting base 17 to the mounting member of a rigid body. In this case, in order to further diminish the vibrating displacement of the portion where the supporting base 17 is connected to the rigid body so as to diminish the leakage of vibrating energy, the length D of the supporting base 17 is made to be more than twice as large as the width W of the supporting arms 16a, 16b.

The vibrator 100 is formed by a photo-etching process from a thin quartz crystal plate which is formed by rotating a Z-cut plate around the X axis through an angle between -5° and $+5^{\circ}$. The vibrator 100 is formed so that the width thereof is along the X axis, the length is along the Y axis and the thickness is along the Z axis of the quartz crystal plate.

The main electrodes 14'a, 14'b, which are provided on the side surfaces of the main vibrating portion 14, respectively, produce an electric field in the direction of the X axis, that is the widthwise direction of the vibrator, whereby the vibrator vibrates in the Y axis direction, that is the lengthwise direction of the vibrator.

In order to make the full use of the electric field produced by the main electrodes 14'a, 14'b and to make the C.I value small so as to improve the vibrating efficiency of the vibrator, the main vibrating portion 14 should be designed so that the width F thereof is small and the thickness is large. By reducing the width F of the main vibrating portion 14, the widthwise

vibration of the main vibrating portion 14 caused by the longitudinal vibration of the same decreases. Consequently, the vibrating energy produced by the main vibrating portion 14 is prevented from leaking out when transmitted to the supporting arms 16a, 16b whereby the vibrating efficiency of the vibrator is improved.

It is desirable to provide something such as thin film electrodes or metal films at the end of the main vibrating portion in order to adjust the frequency of the vibrator. The portion of the main vibrating portion 14 at which such electrodes or metal films are to be provided is hereinafter referred to as the frequency adjusting portion.

As mentioned above, the area of the planar surfaces of the main vibrating portion 14 is small. Consequently, if the frequency adjusting portion is provided on the planar surface thereof in the same manner in Figure 2 and if a metal film is used for adjusting the frequency, the following problems arise:

1. As the area over which the metal films can be provided is small, the rate of the frequency change for a given thickness of film is low. Accordingly, a large quantity of metal is required and adjustment efficiency is poor.

2. Having regard to the strength of the metal film, because the available area is small, the thickness of the film is limited. Consequently, the range of adjustment of the

frequency is narrow and the output is poor.

As is specifically illustrated in Figure 7, therefore, the frequency adjusting portion is provided on the side surface of the main vibrating portion 14 at the end thereof to eliminate the above-mentioned problems. The configuration of the vibrator of Figure 7 is the same as that of Figure 4. The only difference therebetween is that a frequency adjusting portion 23 is provided on the side surface of the main vibrating portion 14 at the end of the half 14a thereof which is not surrounded by the supporting member 18 which is constituted by the connecting portion 15a, 15b, the supporting arms 16a, 16b and the supporting base 17. A metal film formed in this way can be removed even after the vibrator is sealed in a receptacle 21 as shown in Figure 4 by effecting irradiation from outside by means of a laser beam if the receptacle 21 is made of transparent material. The following advantages arise from providing metal film for adjusting the frequency of the vibrator:

1. As the area of side surface of the main vibrating portion is large enough, the rate of frequency change for a given thickness of the metal film is rather large. Accordingly, the amount of metal required is small and the adjustment efficiency is high.
2. By virtue of the range of thickness of the metal film, the distribution of the frequency of the vibrator can be averaged and adjusted. Thus a good output can be

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achieved.

In Figure 7, the frequency adjusting portion 23 is provided on one side surface of the main vibrating portion 14a as an example. However, if the frequency adjusting portion is provided on both side surfaces thereof, more effective frequency adjustment is achieved.

The structure of the end portion of the main vibrating portion of the quartz crystal vibrator which may be used in an assembly according to the present invention is partly depicted in Figures 8, 9 and 10.

In Figure 8, main electrodes 24a, 24b are shown as being provided on the side surfaces and a part of the planar surfaces of a main vibrating portion 24, as shown by slash lines, the frequency adjusting portions are provided in regions 25, 26. In this structure, when plating metal film onto the frequency adjusting portions, there is a problem that the metal films extend to the planar surfaces and reduce the insulation resistance of the main electrodes 24a, 24b.

The embodiments of Figures 9 and 10 have structures such that the above-mentioned problem of insulation deficiency of the main electrodes is eliminated. In the Figure 9 construction, the frequency adjusting portions are indicated at 27, 28 and are provided in the peripheral parts of the planar surfaces of the main vibrating portion. In Figure 10, one main electrode 29'a extends to cover the end portion of the main vibrating portion 29 as shown by the slash line, and the main electrode 29'a is separated from the other main

electrode 29'b.

In order to form this film on the side surface, a masking method may be used. Figure 11 illustrates this masking method wherein a vibrator 30 consists of a main vibrating portion 31, a connecting portion 32a, 32b, supporting arms 33a, 33b and a supporting base 34. Main electrodes 31a, 31b of conductive thin film are deposited on a surface of the vibrator 30. A frame 35 is provided for supporting a certain number of vibrators 30 which are to be mounted on one common wafer. The vibrator 30 is connected to the frame 35 by means of a connector 36. The process of forming electrodes on the side surfaces of the main vibrating portion 31 is described below. First, a mask 39, having openings 37, 38 for forming conductive thin films is put immediately on the vibrator 30. Then conductive thin film material is sputtered through the mask 39 for forming the electrodes on the side surfaces which are electrically connected to the main electrodes 31a, 31b, which main electrodes have been previously formed on the planar surface.

Reference is now made to Figure 12 wherein the process for forming electrodes is illustrated in more detail in chronological order from A to H by sectional views. First, as shown at A, conductive thin films 41a, 41b are deposited on opposite surfaces of a piezo-electric wafer 40. The conductive thin films 41a, 41b are anti-corrosive with respect to the etching solution which is used on the piezo-electric

wafer. As shown at B, on the conductive thin films 41a, 41b photo-resist material 42a, 42b is formed in the configuration of a vibrator. As shown at C, the conductive thin films 41a, 41b are etched into the configuration of the vibrator
5 utilizing the photo-resist material 42a, 42b as anti-corrosive film. As shown at D, the piezo-electric wafer 40 is etched into the configuration of the vibrator utilizing the conductive thin films 41a, 41b as anti-corrosive film, As shown at E, the photo-resist material 42a, 42b is etched
10 into the configuration of the planar surface electrodes. As shown at F, the conductive thin films 41a, 41b are etched in the configuration of the planar surface electrodes utilizing the photo-resist material 42a, 42b as anti-corrosive films. As shown at G, the photo-resist material 42a, 42b is removed.
15 Then, as shown at H, side surface electrodes 44a, 44b are formed by the aforementioned masking method using masks 43a, 43b. In the process shown in Figure 12, the step E which is used to form the photo-resist 42a, 42b into the configuration of the electrode can be inserted after the step C.

20 The above described masking method has the following disadvantages:

1. When bringing a piezo-electric vibrator and a mask into contact with each other, a positional error of less than 10 μ m is required. Moreover, both members must be
25 attached together before being put into the thin film forming

apparatus, which increases the number of steps of the manufacturing process.

2. If the assembly of the vibrator and mask is effected without the accuracy as noted above, the two electrodes may be short circuited or the formation of the thin films on the side surfaces may be insufficient, thus lowering the manufacturing output and also leading to the unstable vibrating characteristics.

Figure 13 shows a series of sectional views which illustrate an electrode forming process in which the above defects of the method described with reference to Figure 12 are eliminated. Here the description of the steps until the piezo-electric wafer is etched into the configuration of the vibrator is omitted because these steps are the same as those described with reference to Figures 12(A) to 12(D). In Figure 13, the steps after the piezo-electric wafer is etched into the configuration of the vibrator are illustrated by steps E' to H'. The reference numeral 40 indicates the main vibrating portion as an example of a part of the vibrator.

First, a conductive thin film 60 is formed over substantially the entire surface of the vibrator 40, as shown at E'.

Photo-resist material 45a, 45b is formed in the configuration of the electrode, as shown at F'. Conductive thin films 41a, 41b, 60a, 60b are etched while utilizing the photo-resist material 45a, 45b as anti-corrosive films as shown at G'.

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Finally, the photo-resist material 45a, 45b is removed, as shown at H'.

The conductive thin films 41a, 41b may also if desired be removed before forming another conductive thin film 60, as in Figure 13(E').

The above-mentioned electrode forming process illustrated in Figure 13 has advantages as follows:

1. The technique required in the steps illustrated in Figure 13 is the same as that of a well-known photo-etching process and an accurate masking technique is not required. Accordingly, the manufacturing cost is reduced.

2. Since the electrodes are formed by a photo-etching process, the configuration of the electrodes is accurately defined. As a result, the characteristics of the vibrators are not likely to vary.

In the process illustrated in Figure 13, it is required to form the photo-resist on the side surface as shown by Figure 13(F'). However, formation of the photo-resist on the side surface is easily achieved by soaking into resist solution, spray coating with a spray gun, or the like.

Although the conductive thin films 41a, 41b, 60 are formed by way of example in a single layer in Figure 13, the process can be also applied in the case of forming thin films in a plurality of layers.

As is apparent from the description so far, in order

to form the main electrodes as a pair of electrodes by splitting, a conductive thin film must be formed on a planar surface and a side surface of the vibrator in a predetermined configuration by an etching process. In general, exposure of the side surface to light so as to obtain the configuration of the electrode is in an oblique direction with respect to the wafer. However, there are some problems with this method. For example, a minute pattern is hard to obtain. Also, because of the necessity to put the wafer and photo-mask in contact with each other, the photo-mask is likely to be damaged, resulting in lowering of output. Further, as the oblique light exposure is required to be performed in two directions with respect to one surface, four light exposures are necessary for both surfaces, which are troublesome.

The structure of the vibrator may, however, be designed to eliminate the above-mentioned problems in the manufacturing process and is described below with reference to Figures 14-16.

Figure 14 illustrates an embodiment of a vibrator forming part of an assembly in accordance with the present invention in which two main electrodes 46a, 46b are formed on a main vibrating portion 46. Recesses 47, 48 are provided at opposite ends of the main vibrating portion 46, respectively and another recess 50 is provided at the fork of a supporting base 49. 51 is a connecting portion between the vibrator and the frame (the vibrator being broken away) and corresponds to 36 in Figure 11.

The recesses 47, 48 are shown in more detail by the enlarged views of Figures 15(A) and 15(B). Figure 15(A) is a plan view of the end portion of the main vibrating portion 46. As shown in Figure 15(A), because of the etching speed anisotropy of piezo-electric material, so called fins 52a, 52b remain after an etching operation is performed at the recess 47 at the end of the main vibrating portion 46. Figure 15(B) is a cross-section taken along a line P-P' of Figure 15(A) and shows that the fins 52a, 52b form slopes 53a, 53b respectively. By this structure, even if the direction of the light is vertical to the piezo-electric wafer, the side surface at the part where the recess is provided can be exposed to the light. Thus, in the portions with the recesses 47, 48, 50, the electrode on the side surface is easily split. The electrode split is also required at the connecting portion 51 in Figure 14. However, at the time when the vibrator is snapped away at the connecting portion 51 between the vibrator and the frame, the electrode is split. Accordingly, there is no need to provide a recess at the connecting portion 51.

The advantages which arise from the structure illustrated in Figure 15 are:

1. As the light exposure of the vibrator is completed only by the light in the direction vertical to the wafer, a precise configuration is obtained.
2. Since light exposure of the projection type is available, the photo-mask is free from being damaged, which leads to a good output.

3. Because the light exposure of the projection type is available, the alignment of the vibrators is easy and a single light exposure is enough. Thus the manufacturing cost is substantially reduced.

5 Figure 16 illustrates another embodiment of a vibrator which may form part of an assembly in accordance with this invention in which the structure as shown in Figure 10 is incorporated in the device of Figure 14. In Figure 16, two electrodes 54a, 54b are shown as being formed on a main
10 vibrating portion 54. In this structure, it is impossible, having regard to the mechanical strength of the part, to provide a recess at the split 55, 56 of the electrodes of the main vibrating portion 54. So only the recess 57 is provided at the fork of the tuning fork type supporting
15 member. In this case, an oblique light exposure is required after the wafer and the photo-mask are disposed in contact with each other. If the recess 57 is not provided, the oblique light exposure is required to be performed twice, that is, in the X direction and in the Y direction which are shown
20 in Figure 16. In contrast, the presence of the recess 57 enables the oblique light exposure to be performed only once in the X direction.

Certain changes of the shape of the above described recess are acceptable. For example, the recess may be
25 triangular or square or may be a circular arc provided that etching of the piezo-electric material will produce a desired fin.

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Further, one of the significant advantages of the photo-etching process is that the ease of performing the process is not affected by the complexity of the configuration to be etched.

C L A I M S

1. A piezo-electric vibrator assembly comprising a sealed receptacle within which is mounted a piezo-electric vibrator of the longitudinal vibration type, the vibrator having a main vibrating portion which vibrates longitudinally and which is provided with main electrodes,
5 a supporting member which supports the main vibrating portion adjacent the point where the vibrating displacement of the latter is smallest, the supporting member having a tuning fork portion whose arms are disposed on opposite sides of a part of the main vibrating portion and whose base is provided with base terminals which are respectively
10 electrically connected to the main electrodes, the resonant frequency of the main vibrating portion being substantially the same as that of the second harmonic of the resonant frequency of the supporting member, and a terminal member which is hermetically sealed to one end of the receptacle and through which extend conductive leads which are
15 electrically connected to the base terminals by means extending over a cross-sectional area greater than that of the conductive leads.
2. An assembly as claimed in claim 1 in which the supporting member also has a connecting portion which extends between the ends of the arms remote from said base and the said point.
- 20 3. An assembly as claimed in claim 1 or 2 in which the arms are parallel to the main vibrating portion.
4. An assembly as claimed in any preceding claim in which the main vibrating portion and the supporting member are integral with each other.



5. An assembly as claimed in any preceding claim in which the conductive leads are rod or plate shaped.
6. An assembly as claimed in any preceding claim in which the terminal member is a press fit in the receptacle.
7. An assembly as claimed in any preceding claim in which metal films are provided on side surfaces at an end portion of the main vibrating portion for adjusting the frequency of the vibrator.
8. An assembly as claimed in any preceding claim in which film electrodes of the same polarity are provided on corresponding side surfaces at an end portion of the main vibrating portion.
9. An assembly as claimed in any preceding claim in which a recess is provided at a part of the main vibrating portion or of the said base where a main electrode or a conductive lead has been split to form a pair thereof.
10. An assembly as claimed in any preceding claim in which the vibrator has been made by a photo-lithographic process comprising forming a piezo-electric wafer into the shape of a vibrator, depositing a conductive thin film over substantially the whole surface of said wafer, forming a photo-resist on said conductive thin film into the shape



of electrodes, etching said conductive thin film to form said electrodes by utilising said photo-resist as a protective film, and removing said photo-resist.

11. A piezo-electric vibrator assembly substantially as hereinbefore described with reference to and as shown in Figures 4-17 of the accompanying drawings.
