

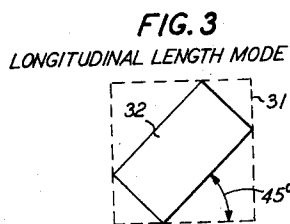
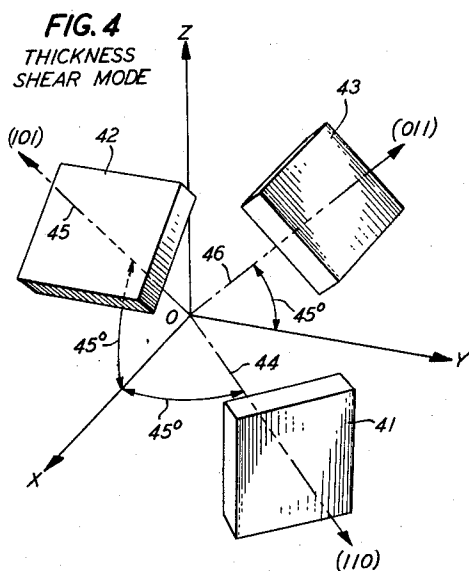
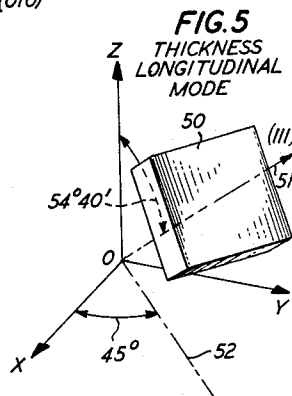
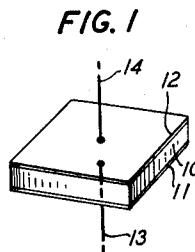
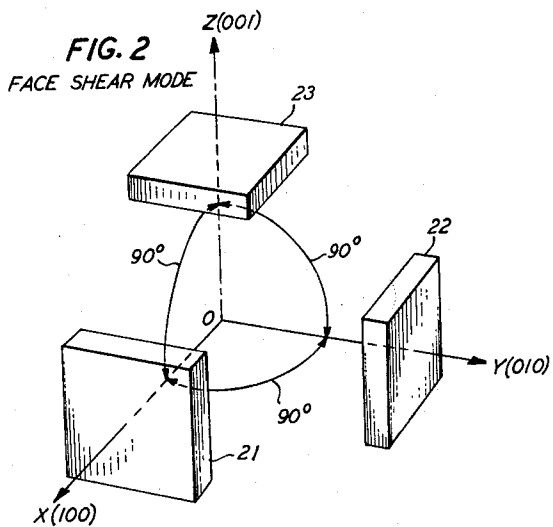
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PRECISION FREQUENCY PIEZOELECTRIC CRYSTALS

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PRECISION FREQUENCY PIEZOELECTRIC  
CRYSTALS

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Continuation of application Ser. No. 833,868, Aug. 14, 1959. This application May 23, 1962, Ser. No. 197,158  
5 Claims. (Cl. 310—9.5)

This invention relates to piezoelectric members. More particularly, it relates to piezoelectric members the mechanical vibrations of which are free from aging effects.

This application is a continuation of applicant's application Serial No. 833, 868 filed August 14, 1959 and entitled "Frequency and Time Standards," now abandoned.

As explained in applicant's Patent 2,998,575, granted August 29, 1961, directed to related subject matter, the most precise prior art piezoelectric crystals which may be employed, for example, as standards of frequency or time or elements of crystal filters, or the like, rely upon the piezoelectrically generated vibrations of quartz crystal members cut at preferred angular orientations with respect to the crystallographic axes of the single crystal from which they are cut.

It is well known, however, that even the best quartz single crystal members are subject to appreciable aging effects, that is, variations with the age of the crystal, which are believed to be caused by dislocation and relaxation effects within the structure of the members, as discussed for example in the paper of applicant, H. E. Bommel and A. W. Warner, published April 1, 1956 in "The Physical Review," volume 102, No. 1, at pages 64 through 71. Many dislocations in such quartz members are believed to result from stresses established during the cutting and forming operations required to obtain members of the specific dimensions and axial alignments required. Difficulties resulting from aging effects in quartz elements are appreciably aggravated by operation at high amplitude.

As is further explained in my above-mentioned patent, semiconductive materials, particularly the materials silicon and germanium with which that patent is principally concerned, are practically free from the aging effects to which quartz crystals are subject, particularly if the latter are driven at higher amplitudes, and are therefore to be preferred in the fabrication of vibratory members for utilization in very stable and high precision crystal filters and frequency and time standards, and the like. A number of the semiconductive materials including silicon and germanium, however, crystallize in the "cubic hexakis-octahedral" or  $O_h$  ( $m3m$ ) class. (See applicant's book entitled "Piezoelectric Crystals and Their Application to Ultrasonics" published by D. Van Nostrand Company, Inc., New York, 1950, particularly Table II at page 18 and the text relevant thereto.) The  $O_h$  ( $m3m$ ) class of crystals, unfortunately, has no piezoelectric properties and therefore must be polarized and driven by electrostatic means as described in detail in my above-mentioned patent. While this can be done, it is obviously less convenient than simply applying electrodes to the major oppositely disposed faces of members of materials which do have piezoelectric properties.

Accordingly, it is a principal object of the present invention to eliminate the difficulties resulting from changes with age and with amplitude of drive of quartz crystal high stability and precision crystal filters and frequency and time standards and at the same time to retain the advantages of the simplicity, effectiveness and economy of members which have piezoelectric properties.

In accordance with the present invention this is ac-

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complished by employing, as high precision elements for crystal filters and frequency and time standards, members cut from single crystals of semiconductive materials which crystallize in the "cubic hexakis-tetrahedral" or  $T_d$  ( $43m$ ) class. (See applicant's above-mentioned book.) Such semiconductive materials have the stability with age and high amplitude of drive common to all semiconductive materials such as silicon and germanium. However, unlike silicon and germanium they also possess piezoelectric properties and hence can be driven piezoelectrically by the simple application of appropriate electrodes and do not require the use of the less convenient electrostatic type of drive described in my above-mentioned patent.

Among the semiconductive materials which crystallize in the cubic hexakis-tetrahedral class are aluminum antimonide, aluminum arsenide, aluminum phosphide, gallium arsenide, gallium antimonide, indium antimonide, indium arsenide, silicon carbide and a number of others. In general, the suitable semiconductive materials are binary compounds, one element being from class III and the other from class V of the atomic table. For the purposes of the present invention the materials employed in the compounds should preferably be pure and the elements should then preferably be "doped" with balancing amounts of  $p$  and  $n$  forming substances to increase the resistivity of the member to a relatively high value so that most of the applied energy will be available for generating mechanical vibration of the member.

The advantageous orientations of any specific member with respect to the crystallographic axes (Miller crystallographic indices) of the single crystal from which the member is cut, for particular modes of vibration which are usually desired, respectively, are discussed hereinunder.

The above and other objects, features and advantages of the invention will become apparent from a perusal of the following specification and the appended claims.

In the drawing:

FIG. 1 represents a rectangular plate-like member cut from a single crystal of a semiconductive material which crystallizes in the cubic hexakis-tetrahedral class, with electrodes assembled on its opposite major faces;

FIG. 2 diagrammatically illustrates the orientations at which a member of the invention should be cut from the single crystal if vibration in the face shear mode is desired;

FIG. 3 diagrammatically represents the orientations at which a member of the invention should be cut from the single crystal if vibration in the longitudinal length mode is desired;

FIG. 4 diagrammatically represents the orientations at which a member of the invention should be cut from the single crystal if vibration in the thickness shear mode is desired; and

FIG. 5 diagrammatically represents the orientations at which a member of the invention should be cut from the single crystal if vibration in the thickness longitudinal mode is desired.

In more detail in FIG. 1, member 10 represents a rectangular plate-like member cut from a single crystal of a semiconductive material of the class which crystallizes in the cubic hexakis-tetrahedral class. The major oppositely disposed surfaces of the member 10 are equipped with conductive electrodes 11 and 12 which may be applied in any of several ways well known and extensively used by those skilled in the art, as for example, by evaporation of a metallic layer on the surface. Electrical conductors 13 and 14 are connected, in any of several ways well known and extensively used by those skilled in the art, to make good electrical contact with

the electrodes 11 and 12, respectively, as shown. Conductors 13 and 14 may be used to connect the member into an electrical circuit (not shown). By way of example, the circuit may be an oscillatory circuit, the frequency response of which it is desired to maintain stable with the passage of time and regardless of the amplitude at which it is driven. (The maximum amplitude should, of course, be less than that which will cause fracture of the member.)

Numerous orientations of member 10 with respect to the crystallographic axes of the single crystal from which it is to be cut may be employed depending upon the mode of vibration to be induced in the member. A number of the more commonly used of the many possible orientations are represented by the diagrams of FIGS 2 through 5, inclusive. These illustrative orientations will be individually discussed hereinafter and the salient characteristics of members of the various orientations discussed will be pointed out.

In FIGS. 2, 4 and 5, the orthogonally related axes intersecting at the origin O and designated X, Y and Z are the crystallographic axes of the crystal. These axes delineate the position of the unit cell of the crystal. Incidentally, in texts concerning crystallography, these same axes are frequently designated as the  $a_1$ ,  $a_2$  and  $a_3$  axes, respectively, and are said to extend in the "[100] directions" of the crystal in accordance with the conventional Miller crystallographic indices. More specifically, as is well known and universally understood by those skilled in the art, the X-axis, commonly known as the electrical axis, defines the [100] direction, the Y-axis, commonly known as the mechanical axis, defines the [010] direction and the Z-axis, commonly known as the optic axis, defines the [001] direction.

In FIG. 2, plates 21, 22 and 23 represent the orientations of cuts from a single crystal in which the major surfaces of the rectangular plate members are perpendicular to the X, Y and Z axes, respectively, and the pairs of minor side surfaces of the members are parallel to one or the other of the remaining two of the three axes, respectively, as shown.

Plates 21, 22 and 23 will each vibrate in what is known to those skilled in the art as the "face shear mode" when driven piezoelectrically by electrodes placed on their major surfaces as illustrated in FIG. 1. As the resonant frequency in this mode of vibration is determined by the contour of the plate, the resonant frequencies of plates 21, 22 and 23, respectively, will be relatively low.

In FIG. 3 broken line 31 represents the contour of a major surface of any one of the cuts as illustrated by plates 21, 22 or 23 of FIG. 2. If a plate 32 is cut from plate 31 so that its edges are at an angle of 45 degrees with respect to the edges of plate 31, as shown, then plate 32 will vibrate in the "longitudinal length mode" when driven piezoelectrically by conductive electrodes placed on its major surfaces as illustrated in FIG. 1. Since the resonant frequency of such a member is determined by its length or longest dimension it will, in general, be resonant at a frequency somewhat lower than a member of comparable size which vibrates in the face shear mode.

In FIG. 4, another set of three rectangular plate members 41, 42 and 43 is shown which vibrates in the "thickness shear mode" when driven piezoelectrically by conductive electrodes arranged as illustrated in FIG. 1. These plates have their major surfaces perpendicular to a "[110]" direction, that is to either the [110] direction per se, or the [101] direction or the [011] direction. The [110] direction represented by broken line 44 lies in the plane of the X and Y axes and makes an angle of 45 degrees with each of these axes. Similarly, the [101] direction represented by broken line 45 lies in the plane of the X and Z axes and makes an angle

of 45 degrees with each of these axes. Finally, the [011] direction represented by broken line 46 lies in the plane of the Y and Z axes and makes an angle of 45 degrees with each of these axes.

Since the resonant frequency of a member vibrating in the thickness shear mode is determined mainly by the thickness of the element, it will have a relatively high frequency of resonance.

In FIG. 5 a further rectangular plate member 50 is shown which will vibrate in the "thickness longitudinal mode" when driven piezoelectrically by electrodes arranged as illustrated in FIG. 1. This plate has its major surfaces perpendicular to the [111] direction, which as represented by broken line 51, is the direction along a line extending from the origin O in such manner that each point along line 51 is equidistant from all three of the axes. The projection of line 51 on the plane of any two of the axes is a line, such as broken line 52 in the XY plane, for example, which makes an angle of 45 degrees with each of the two axes defining the plane. Furthermore, broken line 51 makes an angle of 54 degrees 40 minutes with each of the axes, X, Y and Z. Since the resonant frequency of a member vibrating in the "thickness longitudinal mode" is dependent mainly on the thickness of the member, it will also have a relatively high frequency of resonance.

While convenient for many purposes, it is not essential that members of rectangular shape be employed, since members of circular, ovoid or other contours the vibratory characteristics of which are appropriate may also, obviously, be used.

Numerous and varied other arrangements and variations of the arrangements discussed hereinabove for illustrative purposes can readily be devised by those skilled in the art without departing from the spirit and scope of the principles of the present invention.

What is claimed is:

1. A piezoelectric member, the member being of a material selected from the class consisting of aluminum antimonide, aluminum arsenide, aluminum phosphide, gallium arsenide, gallium antimonide, indium antimonide, indium arsenide, and silicon carbide, the member comprising a plate of the material cut with a predetermined orientation with respect to the crystallographic axes, from a single crystal of the material, the material containing balancing amounts of  $p$  and  $n$  forming substances sufficient to substantially increase its resistance, a pair of conductive electrodes applied to oppositely disposed major surfaces of the member and conductive leads connected electrically to the electrodes.

2. The member of claim 1 in which the member is cut from a single crystal with its major surfaces perpendicular to a first one of the crystallographic axes and its edge surfaces parallel to one or the other of a second one and a third one of the crystallographic axes, respectively.

3. The member of claim 1 in which the member is cut from a single crystal with its major surfaces perpendicular to a line in the plane defined by two of the crystallographic axes, the line making an angle of 45 degrees with each of the two axes.

4. The member of claim 1 in which the member is cut from a single crystal with its major surfaces perpendicular to a line extending from the intersection of the three crystallographic axes in a direction for which each point along the line is equidistant from all three of the crystallographic axes.

5. The member of claim 1 in which the member is cut from a single crystal with its major surfaces perpendicular to a first one of the crystallographic axes and its edge surfaces inclined at an angle of 45 degrees to one or the other of a second one and a third one of the crystallographic axes, respectively.