Oct. 5, 1948. W. P. MASON 2,450,434

PIEZOELECTRIC CRYSTAL APPARATUS

Filed April 4, 1946

FIG. 1

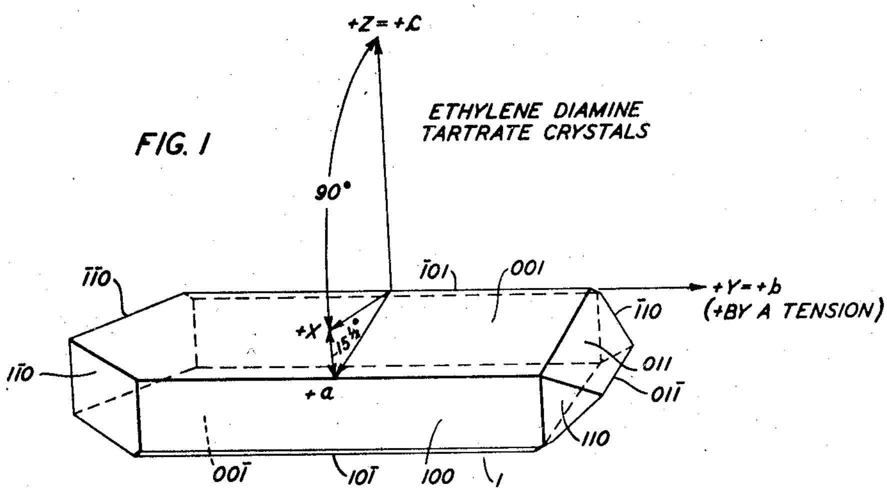


FIG. 2

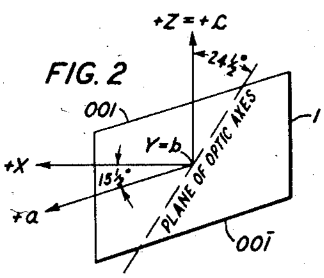
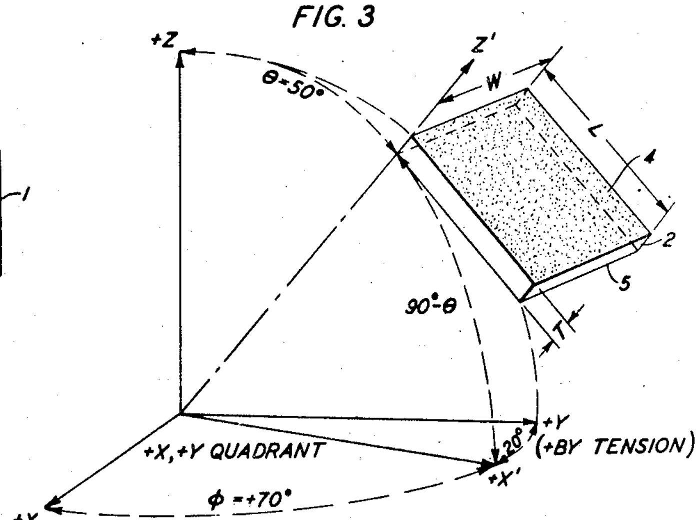


FIG. 3



L.M. CUT-THICKNESS
LONGITUDINAL MODE
L=W

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Patented Oct. 5, 1948

2,450,434

UNITED STATES PATENT OFFICE

2,450,434

PIEZOELECTRIC CRYSTAL APPARATUS

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Application April 4, 1946, Serial No. 659,469

15 Claims. (Cl. 171—327)

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This invention relates to crystal apparatus and particularly to thickness-longitudinal mode type piezoelectric crystal elements comprising ethylene diamine tartrate ($C_6H_{14}N_2O_6$). Such crystal elements may be used as frequency controlling circuit elements in electric wave filter systems, oscillation generator systems and amplifier systems. Also, they may be utilized as modulators, or as harmonic producers, or as electromechanical transducers in sonic or supersonic projectors, microphones, pick-up devices and detectors.

One of the objects of this invention is to provide an efficient low-loss cut or orientation capable of producing a longitudinal thickness mode of motion in crystal elements made from synthetic crystalline ethylene diamine tartrate.

Another object of this invention is to take advantage of the high piezoelectric coupling, the low ratio of capacities, the low cost and other advantages of crystalline ethylene diamine tartrate.

Other objects of this invention are to provide a crystal element comprising ethylene diamine tartrate that may possess useful characteristics, such as effective piezoelectric constants, and small coupling of the desired mode of motion to undesired modes of motion therein.

A particular object of this invention is to provide a synthetic ethylene diamine tartrate crystal element having maximum piezoelectric coupling for the thickness-longitudinal mode of motion.

Ethylene diamine tartrate is a salt of tartaric acid having a molecule which lacks symmetry elements. In its crystalline form, it lacks a center of symmetry and belongs to a crystal class which is piezoelectric and which is the monoclinic sphenoidal crystal class. By virtue of its structure, ethylene diamine tartrate will form crystals offering high piezoelectric constants. In addition, the crystalline material affords certain cuts with low dielectric loss and mechanical dissipation. Also crystalline ethylene diamine tartrate has no water of crystallization and hence will not dehydrate when used in air or in vacuum.

Crystal elements of suitable orientation cut from crystalline ethylene diamine tartrate may be excited in different modes of motion such as the longitudinal length or the longitudinal width modes of motion, or the thickness shear or the thickness longitudinal modes of motion controlled mainly by the thickness dimension. These various modes of motion are similar in the general form of their motion to those of similar or corresponding names that are already known in connection with other crystalline substances such as quartz, Rochelle salt and ammonium dihydrogen phosphate crystal elements.

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It is useful to have a synthetic type of piezoelectric crystal element having a very high piezoelectric or electromechanical coupling with low loss, for efficiently producing a thickness longitudinal mode of motion therein. In accordance with this invention, such a synthetic type crystal cut may be provided in the form of tartrate crystals and the tartrate crystals may be suitable cuts taken from crystalline ethylene diamine tartrate adapted to operate in a thickness longitudinal mode of motion.

In the case of ethylene diamine tartrate ($C_6H_{14}N_2O_6$), which has no water of crystallization, there are among other useful cuts, thickness longitudinal mode crystal elements which may be used, for example, in a delay circuit system for setting up longitudinal waves in a mercury or water column for example, or as a circuit element in an electric wave filter system, or as a circuit element for the frequency control of oscillators. Such crystal elements may be used as acceptable substitutes for quartz and other crystal elements in oscillator, filter and other crystal systems.

In accordance with this invention, the crystal elements cut from crystalline ethylene diamine tartrate may be rotated Z-cut type crystal elements having the thickness dimension or the normal Z′ to their major faces disposed at acute angles with respect to all three of the mutually perpendicular X, Y and Z axes, and operating in the thickness longitudinal mode of motion along the shortest or thickness dimension thereof. For maximum piezoelectric coupling, the plate normal or thickness dimension may be inclined at an angle θ of about 50 degrees with respect to the +Z axis and may lie in the +X, +Y quadrant in the plane of the ZZ′ axes, the ZZ′ plane being inclined in the region of Φ= about +70 degrees with respect to the +X axis or about 20 degrees from the +Y axis as measured in the XY plane.

The synthetic tartrate crystal elements provided in accordance with this invention have high electromechanical coupling of the order of 20 to 25 per cent or more, and a small dielectric loss. These advantageous properties together with the low cost and freedom from supply troubles indicate that these crystal elements may be used in place of quartz or other crystals as circuit elements. Moreover, since the high electromechanical coupling existing in these crystals allows the circuit frequency to be varied in much larger amounts by a reactance tube, than can be done for the frequency of quartz, such tartrate crystal cuts may be advantageously used for frequency modulating an oscillation generator. On account of the large electromechanical coupling, the frequency variation and shift may be of large value and may be controlled by an applied direct current voltage or by a suitable reactance tube, for example.

For a clearer understanding of the nature of this invention and the additional advantages, features and objects thereof, reference is made to the following description taken in connection with the accompanying drawings, in which like reference characters represent like or similar parts and in which:

Fig. 1 is a perspective view illustrating the form and growth habit in which a monoclinic crystal of ethylene diamine tartrate may crystallize, and also illustrating the relation of the surfaces of the mother crystal with respect to the mutually perpendicular X, Y and Z axes, and the crystallographic *a*, *b* and *c* axes;

Fig. 2 is an edge view illustrating the rectangular X, Y and Z and the crystallographic *a*, *b* and *c* systems of axes for monoclinic crystals, and also illustrating the plane of the optic axes of ethylene diamine tartrate crystals; and

Fig. 3 is a perspective view illustrating thickness longitudinal mode type ethylene diamine tartrate crystal elements rotated in effect to a position corresponding to an angle of θ in the region of about 50 degrees with respect to the +Z axis and an angle of Φ in the region of +70 degrees with respect to the +X axis.

This specification follows the conventional terminology, as applied to piezoelectric crystalline substances, which employs a system of three mutually perpendicular X, Y and Z axes as reference axes for defining the angular orientation of a crystal element. As used in this specification and as shown in the drawing, the Z axis corresponds to the *c* axis, the Y axis corresponds to the *b* axis, and the X axis is inclined at an angle with respect to the *a* axis which, in the case of ethylene diamine tartrate, is an angle of about 15½ degrees. The crystallographic *a*, *b* and *c* axes represent conventional terminology as used by crystallographers.

Referring to the drawing, Fig. 1 is a perspective view illustrating the general form and growth habit in which ethylene diamine tartrate may crystallize, the natural faces of the ethylene diamine tartrate mother crystal 1 being designated in Fig. 1 in terms of conventional terminology as used by crystallographers. For example, the top surface of the crystal body 1 is designated as a 001 plane, and the bottom surface thereof as a $00\bar{1}$ plane, and the other surfaces and facets thereof are as shown in Fig. 1.

The mother crystal 1, as illustrated in Fig. 1, may be grown from any suitable nutrient solution by any suitable crystallizer apparatus or method, the nutrient solution used for growing the crystal 1 being prepared from any suitable chemical substances and the crystal 1 being grown from such nutrient solution in any suitable manner to obtain a mother crystal 1 of a size and shape that is suitable for cutting therefrom piezoelectric crystal elements in accordance with this invention. The mother crystal 1 from which the crystal elements 2 are to be cut is relatively easy to grow in shapes and sizes that are suitable for cutting useful crystal plates or elements 2 therefrom. Such mother crystals 1 may be conveniently grown to sizes around 2 inches or more for the X, Y and Z dimensions or of any sufficient size to suit the desired size for the piezoelectric circuit elements 2 that are to be cut therefrom. It will be understood that the mother crystal 1 may be grown to size by any suitable crystallizer apparatus such as, for example, by a rocking tank type crystallizer or by a reciprocating rotary gyrator type crystallizer.

Crystals 1 comprising ethylene diamine tartrate have no water of crystallization and hence no vapor pressure, and may be put in an evacuated container without change, and may be held in temperatures as high as 100° C. At a temperature of about 130° C., some surface decomposition may start. A crystal 1 comprising crystalline ethylene diamine tartrate has only one cleavage plane which lies along the 0,0,1 crystallographic plane. While cleavage planes may make the crystals 1 somewhat more difficult to cut and process, nevertheless satisfactory processing may be done by any suitable means such as, for example, by using a sanding belt cooled by oil or by a solution of water and ethylene glycol, for example.

Monoclinic crystals 1 comprising ethyelne diamine tartrate are characterized by having two crystallographic axes *b* and *c*, which are disposed at right angles with respect to each other, and a third crystallographic axis *a* which makes an angle different than 90 degrees from the other two crystallographic axes *b* and *c*. The *c* axis lies along the longest direction of the unit cell of the crystalline material. The *b* axis is an axis of two-fold or binary symmetry. In dealing with the axes and the properties of such a monoclinic crystal 1, it is convenient and simpler to use a right-angled or mutually perpendicular system of X, Y and Z coordinates. Accordingly, as illustrated in Fig. 1, the method chosen for relating the conventional right-angled X, Y and Z system of axes to the *a*, *b* and *c* system of crystallographic axes of the crystallographer is to make the Z axis coincide with the *c* axis and the Y axis coincide with the *b* axis, and to have the X axis lie in the plane of the *a* and *c* crystallographic axes at an angle with respect to the *a* axis, the X axis angle being about 15 degrees 30 minutes above the *a* axis for ethylene diamine tartrate, as shown in Figs. 1 and 2.

The X, Y and Z axes form a mutually perpendicular system of axes, the Y axis being a polar axis which is positive (+) by a tension at one of its ends, as shown in Fig. 1. In order to specify which end of the Y axis is the positive end, the plane of the optic axes of the crystal 1 may be located. A monoclinic crystal 1 is an optically biaxial crystal and for crystalline ethylene diamine tartrate, the plane that contains these optic axes is found to be parallel to the *b* or Y crystallographic axis and inclined at an angle of about 24½ degrees with respect to the +Z axis, as illustrated in Fig. 2.

Fig. 2 is a diagram illustrating the plane of the optic axes for crystals 1 comprising ethylene diamine tartrate. As shown in Fig. 2, the plane of the optic axes of an ethylene diamine tartrate crystal 1 is parallel to the Y or *b* axis, which in Fig. 2 is perpendicular to the surface of the drawing; and is inclined in a clockwise direction at an angle of about 24½ degrees from the +Z or +*c* crystallographic axis. Since the +X axis lies at a counter-clockwise angle of 90 degrees from the +*c* or +Z axis, and the +*b*=+Y axis makes a right angle system of coordinates with the X and Z axes, the system illustrated in Fig.

2 determines the positive (+) directions of all three of the X, Y and Z axes. Hence, the positive directions of all three X, Y and Z axes may be specified with reference to the plane of the optic axes of the crystal 1. A similar optical method of procedure may be used for orienting and specifying the direction of the three mutually perpendicular X, Y and Z axes of other types of monoclinic crystals. Oriented crystal cuts are usually specified in practice by known X-ray orientation procedures.

Fig. 3 is a perspective view illustrating a crystal element 2 comprising ethylene diamine tartrate that has been cut from a suitable mother crystal 1 as shown in Fig. 1. The crystal element 2 as shown in Fig. 3 may be made into the form of a plate of substantially rectangular parallelepiped shape having a length dimension L, a breadth or width dimension W, and a thickness or thin dimension T, the directions of the dimensions L, W and T being mutually perpendicular, and the thin or thickness dimension T being measured between the opposite major or electrode faces of the crystal element 2. The dimension L and the dimension W of the crystal element 2 may be made of values to avoid spurious modes of motion in the crystal element 2. The thickness or thin dimension T may be made of a value to suit the impedance or frequency of the system in which the crystal element 2 may be utilized as a circuit element. The dimensions L and W may be made of suitable values to avoid nearby spurious modes of motion which, by proper dimensioning of the larger dimensions L and W relative to the smaller thickness dimension T, may be placed in a location that is relatively remote from the desired thickness longitudinal mode of motion along the thickness dimension T.

Suitable conductive electrodes 4 and 5 may be provided adjacent the two opposite major or electrode faces of the crystal element 2 in order to apply electric field excitation thereto. The electrodes 4 and 5 when formed integral with the faces of the crystal element 2 may consist of gold, platinum, silver, aluminum or other suitable conductive material deposited upon surfaces of the crystal element 2 by evaporation in vacuum or by other suitable process. The electrodes 4 and 5 may be electrodes wholly or partially covering the major faces of the crystal element 2, and may be provided in divided or nondivided form as already known in connection with other thickness mode crystals. Accordingly, it will be understood that the crystal elements 2 disclosed in this specification may be provided with conductive electrodes or coatings 4 and 5 on their faces of any suitable composition, shape and arrangement, such as those already known in connection with Rochelle salt or quartz crystals, for example; and that they may be mounted and electrically connected by any suitable means, such as, for example, by pressure type clamping means or by conductive supporting spring wires cemented by conductive cement or glued to the crystal element and to the metallic coatings 4 and 5 deposited on the crystal element 2, as already known in connection with quartz, Rochelle salt or other crystals having similar or corresponding thickness longitudinal modes of motion.

As illustrated in Fig. 3, the crystal element 2 has its major faces so disposed that the perpendicular or normal Z' thereto and the thickness dimension T thereof is disposed in the +X, +Y quadrant and is inclined at an angle θ=about 50 degrees with respect to the +Z axis, and lies in the ZZ' plane which is inclined at an angle in the region of about 20 degrees from the +Y axis and at a Φ angle of about 70 degrees with respect to the +X axis, as measured in the XY plane, the XY plane in the case of ethylene diamine tartrate being spaced about 15½ degrees from the plane of the *a* and *b* axes. At the angles of θ=about 50 degrees with respect to the +Z axis and Φ=about 70 degrees with respect to the +X axis as particularly illustrated in Fig. 3, the crystal element 2 has a maximum value of piezoelectric coupling for its longitudinal mode of motion along the thickness dimension T.

As particularly illustrated in Fig. 3, while the dimension L edges of the major faces of the crystal element 2 lie substantially in the plane of the Z' and Z axes, they may be disposed or inclined at other positions with the thickness dimension T extending along the Z' axis. The electrodes 4 and 5 disposed adjacent the major faces of the crystal element 2 provide an electric field in the direction of the thickness dimension T of the crystal element 2 thereby producing a useful longitudinal mode of motion along the thickness dimension T of the crystal element 2 with very high electromechanical coupling.

The dimensional ratio of the width dimension W with respect to the length dimension L of the crystal element Z may be made of any suitable value such as in the region of 1.0, for example, and as particularly described herein is made about 1.0 for longitudinal thickness mode crystal elements 2. Other values of dimensional ratios of the width W with respect to the length L, as of the order of 1.0 more or less, may be used to space spurious modes of motion at a frequency which is remote from the fundamental longitudinal mode of motion along the thickness dimension T. Moreover, while rectangular shaped crystal elements 2 have been particularly described, the major faces thereof instead of being square or rectangular may be circular.

When the crystal element 2 is operated in the fundamental longitudinal mode of motion along the thickness dimension T thereof, the crystal element 2 may be mounted and electrically connected by any suitable means such as by wires cemented to the crystal element 2 and the metallic coatings 4 and 5 in the edge regions of the crystal element 2.

Fig. 3 also may be taken to illustrate ethylene diamine tartrate crystal elements 2 cut from a mother crystal 1 such as that illustrated in Fig. 1, and having an orientation similar to that of the θ=50-degree and Φ=70-degree crystal element 2 particularly illustrated in Fig. 3, except for the position of the thickness dimension T thereof, which may be inclined at other acute angles with respect to all three of the mutually perpendicular X, Y and Z axes. The electrodes 4 and 5 disposed adjacent the major faces of the crystal element 2 provide an electric field in the general direction of the thickness dimension T of the crystal element 2, thereby producing a useful longitudinal mode of motion along the thickness dimension T of the crystal element 2 with a high electromechanical coupling.

The main mode of motion, which is the fundamental longitudinal mode of vibration along the Z' axis thickness dimension T has a frequency constant of about 1,520 kilocycles per second per millimeter of the thickness dimension T. Thus, as an example, a crystal element 2 having a thickness dimension T of one millimeter and a dimensional ratio of width W to length L of about 1.0 for the large dimensions L and W will have a frequency of about 1,520 kilocycles per second for its fundamental longitudinal mode of motion along the Z' axis thickness dimension T. A similar crystal element 2 having a thickness dimension T of another value will have a corresponing frequency which varies inversely as the value of its thickness dimension T. The effect of the secondary modes of motion upon the main thickness longitudinal mode of motion is comparatively negligible.

The particular angle of cut for the ethylene diamine tartrate crystal element 2 illustrated in Fig. 3 is suitable for setting up longitudinal waves in a mercury or water column of a delay circuit for use in a radio system. In the delay line for a radio circuit, a considerable loss may be caused by a low coupling in the crystal and the high impedance of the mercury in the associated mercury column. A lower loss in such a delay system may be obtained by the use of an ethylene diamine tartrate crystal element 2, the constants of which are roughly 39×10^{-8} for the thickness longitudinal mode piezoelectric constant 1.5×10^{11} for the thickness mode stiffness or elastic constant C_{33}, 6.5 for the dielectric constant K, and 1.633 for the density ρ.

It will be noted that among the advantageous cuts illustrated in Fig. 3 is an orientation for which the piezo electric coupling coefficient may be a maximum value. The high electromechanical coupling, the high reactance-resistance ratio Q, the ease of procurement, the low cost of production and the freedom from water of crystallization in such ethylene diamine tartrate crystal elements are advantages of interest for use as circuit elements in electrical systems generally.

Although this invention has been described and illustrated in relation to specific arrangements, it is to be understood that it is capable of application in other organizations and is, therefore, not to be limited to the particular embodiments disclosed.

What is claimed is:

1. Crystal apparatus comprising an ethylene diamine tartrate crystal element of high electromechanical coupling having major faces, the normal to said major faces lying in a plane which is disposed substantially 70 degrees from the +X axis and 20 degrees from the +Y axis as measured in the XY plane, said normal being inclined at an angle of substantially 50 degrees with respect to the +Z axis.

2. A thickness longitudinal mode ethylene diamine tartrate crystal element of high electromechanical coupling having substantially rectangular major faces, the normal or thickness dimension between said major faces lying a plane which is disposed substantially 20 degrees from the +Y axis and 70 degrees from the +X axis as measured in the +X, +Y quadrant, said thickness dimension being disposed at an angle of substantially 50 degrees with respect to the +Z axis.

3. A thickness longitudinal mode ethylene diamine tartrate crystal element of high electromechanical coupling having substantially square major faces, the normal or thickness dimension thereof lying in a ZZ' plane which is disposed substantially 70 degrees from the +X axis and 20 degrees from the +Y axis as measured in the XY plane, said thickness dimension being disposed at an angle of substantially 50 degrees with respect to the +Z axis.

4. A thickness longitudinal mode ethylene diamine tartrate crystal plate of high electromechanical coupling having its normal or thickness dimension lying in a ZZ' plane which is disposed substantially 70 degrees from the +X axis as measured in the XY plane in the +X, +Y quadrant, said thickness dimension of said crystal plate being disposed at an angle of substantially 50 degrees with respect to the +Z axis.

5. A thickness longitudinal mode ethylene diamine tartrate crystal element of high electromechanical coupling having substantially square major faces, the normal or thickness dimension thereof lying in a ZZ' plane which is disposed in the +X, +Y quadrant substantially +70 degrees from the +X axis as measured in the XY plane, said thickness dimension of said crystal element being disposed at an angle of substantially 50 degrees with respect to the +Z axis, and said major faces having an edge lying in said ZZ' plane.

6. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element having substantially rectangular major faces, the normal to said major faces lying in a ZZ' plane which is disposed in the +X, +Y quadrant substantially +70 degrees from the +X axis as measured in the XY plane, said normal to said major faces being disposed at an angle of substantially 50 degrees with respect to the +Z axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in a longitudinal mode of motion along said normal or thickness dimension of said crystal element.

7. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element having substantially square major faces, the normal to said major faces lying in a ZZ' plane which is disposed substantially +70 degrees from the +X axis as measured in the XY plane, said normal to said major faces being disposed at an angle of substantially 50 degrees with respect to the +Z axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in a longitudinal mode of motion along said normal or thickness dimension of said crystal element.

8. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element having substantially parallel major faces, the normal to said major faces lying in a ZZ' plane which is disposed substantially +70 degrees from the +X axis as measured in the XY plane, said normal to said major faces being disposed at an angle of substantially 50 degrees with respect to the +Z axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in a longitudinal mode of motion along said normal or thickness dimension of said crystal element.

9. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element of high electromechanical coupling for its thickness longitudinal mode of motion, said crystal element having substantially square major faces, the normal to said major faces being disposed at acute angles with respect to all three of the mutually perpendicular X, Y and Z axes, said angles being values corresponding to said high and substantially maximum value of said electromechanical coupling, and one of said angles being an angle of substantially 50 degrees with respect to said Z axis, and means comprising electrodes disposed adjacent said major faces for operating said crys-

tal element in said longitudinal mode of motion along said normal or thickness dimension of said crystal element.

10. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element of high electromechanical coupling for its thickness longitudinal mode of motion, said crystal element having substantially rectangular major faces, the normal to said major faces being disposed at acute angles with respect to all three of the mutually perpendicular X, Y and Z axes, said angles being values corresponding to said high and substantially maximum value of said electromechanical coupling, and one of said angles being an angle of substantially 50 degrees with respect to said Z axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in said longitudinal mode of motion along said normal or thickness dimension of said crystal element.

11. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element of high electromechanical coupling for its thickness longitudinal mode of motion, said crystal element having major faces, the normal to said major faces being disposed at acute angles with respect to all three of the mutually perpendicular X, Y and Z axes, said angles being values corresponding to said high and substantially maximum value of said electromechanical coupling, and one of said angles being an angle of substantially 50 degrees with respect to said Z axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in said longitudinal mode of motion along said normal or thickness dimension of said crystal element.

12. Crystal apparatus comprising an ethylene diamine tartrate crystal element, the thickness dimension between the major faces of said crystal element lying in a plane which is disposed substantially 20 degrees from the +Y axis and 70 degrees from the +X axis as measured in the XY plane, said thickness dimension of said major faces being disposed at an angle of substantially 50 degrees with respect to the +Z axis, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in a longitudinal mode of motion along said thickness dimension.

13. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element of high electromechanical coupling adapted for longitudinal motion along the thickness dimension between its substantially square major faces, said thickness dimension lying in a plane which is disposed substantially 20 degrees from the +Y axis and 70 degrees from the +X axis as measured in the XY plane of the three mutually perpendicular X, Y and Z axes, and said thickness dimension being disposed at an angle of substantially 50 degrees with respect to said +Z axis, said thickness dimension being a value corresponding to the frequency for said longitudinal mode of motion, said thickness dimension expressed in millimeters being one of the values substantially from 1,400 to 1,600 divided by the value of said frequency expressed in kilocycles per second, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in said longitudinal mode of motion.

14. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element of high electromechanical coupling adapted for longitudinal motion along the thickness dimension between its substantially rectangular major faces, said thickness dimension lying in a plane substantially +70 degrees from the +X axis as measured in the XY plane of the three mutually perpendicular X, Y and Z axes, and said thickness dimension being disposed at an angle of substantially 50 degrees with respect to said +Z axis, said thickness dimension being a value corresponding to the frequency for said longitudinal mode of motion, said thickness dimension expressed in millimeters being one of the values substantially from 1,400 to 1,600 divided by the value of said frequency expressed in kilocycles per second, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in said longitudinal mode of motion.

15. Piezoelectric crystal apparatus comprising an ethylene diamine tartrate crystal element of high electromechanical coupling adapted for longitudinal motion along the thickness dimension between its substantially parallel major faces, said thickness dimension lying in a plane which is in the +X, +Y quadrant and which is disposed substantially 70 degrees from the +X axis as measured in the XY plane of the three mutually perpendicular X, Y and Z axes, and said thickness dimension being disposed at an angle of substantially 50 degrees with respect to said +Z axis, said thickness dimension being a value corresponding to the frequency for said longitudinal mode of motion, said thickness dimension expressed in millimeters being one of the values substantially from 1,400 to 1,600 divided by the value of said frequency expressed in kilocycles per second, and means comprising electrodes disposed adjacent said major faces for operating said crystal element in said longitudinal mode of motion.

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