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XR 3,591,813
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United States

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[54] LITHIUM NIOBATE TRANSDUCERS

7 Claims, 7 Drawing Figs.

[52] **U.S. Cl.** **310/9.5,** 252/62.9
[51] **Int. Cl.** **H01v 7/00**
[50] **Field of Search** 310/9.5; 252/62.9

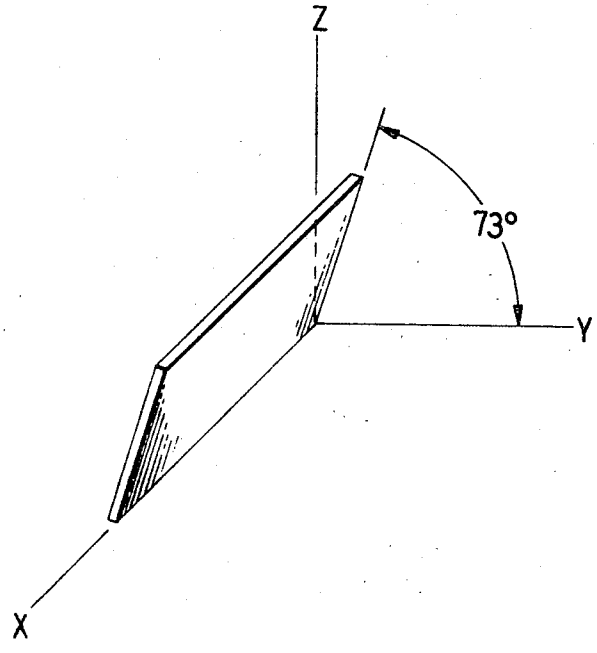
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Attorneys—R. J. Guenther and Arthur J. Torsiglieri

ABSTRACT: The specification describes ultrasonic transducers made from single crystal lithium niobate. Five crystal orientations are given for which transducer characteristics are especially favorable.



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SHEET 1 OF 2

FIG. 1

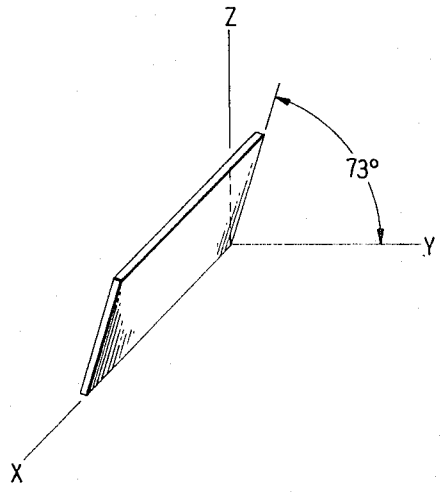


FIG. 2

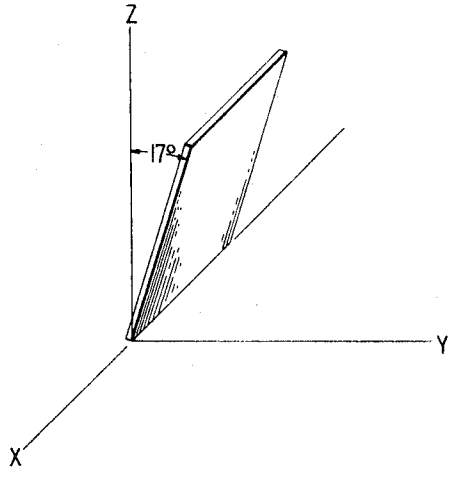
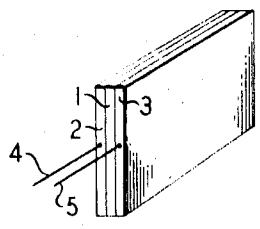


FIG. 6



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FIG. 3

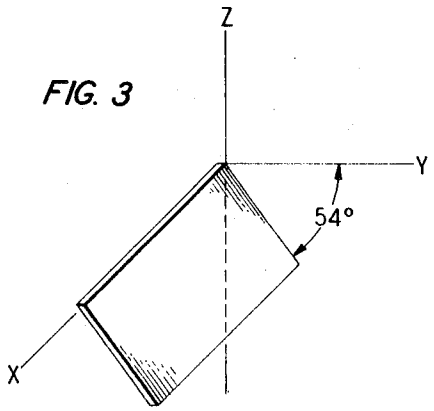


FIG. 4

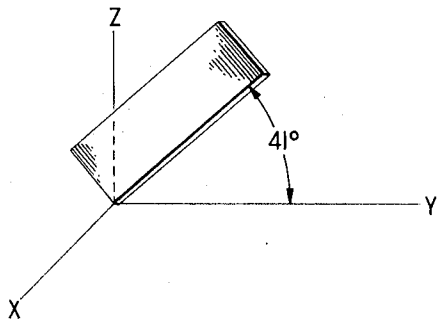


FIG. 5

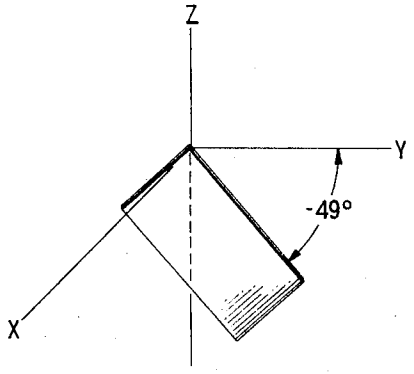
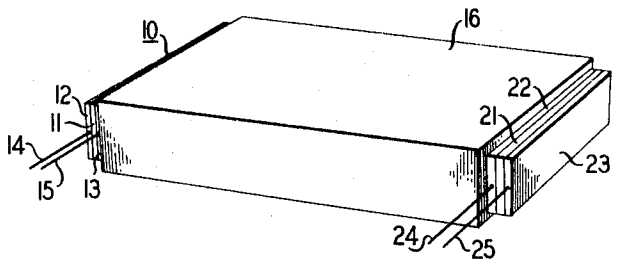


FIG. 7



LITHIUM NIOBATE TRANSDUCERS

This invention relates to piezoelectric crystals of lithium niobate and to ultrasonic transducers employing these crystals.

Recent interest in crystals in the class ($3m$) has uncovered new piezoelectric materials. Much interest has centered around lithium tantalate in this regard (see *Journal of the American Ceramic Society*, 48, 112 (1965)).

It has now been found that certain crystal orientations exist in lithium niobate which for transducer applications have piezoelectric properties superior to those previously obtained with lithium tantalate. Crystals in class ($3m$) have a low degree of symmetry and the useful orientations have not previously been recognized for $LiNbo_3$. Useful orientations are those that result in transducers vibrating in predominantly a single mode and having a high effective electromechanical coupling factor. A further important property, which is favorably exhibited by lithium niobate, is a low dielectric constant for all orientations.

Several crystal orientations have been found for $LiNbO_3$ which result in transducers having coupling factors in excess of 50 percent and which have sufficient modal purity that propagation of energy in spurious modes is more than 40 db. below the signal level of the main mode. In addition to the high level of performance obtainable from $LiNbO_3$ transducers, this material has the additional advantages that it is presently available commercially and possesses mechanical properties that enable it to withstand the processing required to prepare plates sufficiently thin for high frequency applications.

The devices for which $LiNbO_3$ is particularly suited are ultrasonic transducers operating at relatively high frequencies, i.e. above 100 mHz. Ultrasonic delay lines for digital storage at those frequencies are currently being developed. High frequency ultrasonic transducers are also useful in acousto-optic devices such as ultrasonic light deflectors and ultrasonic light modulators.

The crystal orientations which form the basis for this invention are rotated Y-cut crystals having orientations designated (zxl) 73°, (yzw) −17°, and (zxl) −54° and X-cut crystals designated (xyt) 41°, and (xyt) −49°.

These five crystal designs and their application will be described more completely in the following detailed description.

In the drawing:

FIGS. 1 to 5 are geometric representations of the inventive crystal orientations;

FIG. 6 is a perspective view of an ultrasonic transducer incorporating one of the crystals of the invention; and

FIG. 7 is a perspective view of an ultrasonic device incorporating the transducer of FIG. 6.

Rotated Y-cut plates of $LiNbO_3$ can vibrate in a pure shear mode with particle displacement along the X-axis or in either a quasi-shear or a quasi-longitudinal mode of vibration, with particle displacement normal to the X-axis but neither normal nor parallel to the plane of the plate. An electric field applied in the thickness direction will not excite the pure shear mode but in most cases will excite both the quasi-shear and quasi-longitudinal modes simultaneously. However, there are four rotated Y-cuts where an electric field in the thickness direction excites only one mode, the angles of rotation being 36°, 90° (Z-cut), 123°, and 163°. Two of these four, the 36° and 163° cuts, are most useful for transducer applications.

The 163° rotated Y-cut plate, a (zxl) +73° cut in IRE notation, has no coupling to the quasi-longitudinal mode and an effective coupling factor of 61 percent for the quasi-shear mode. The particle displacement for this mode is 1.7° from the plane of the plate so that it is very near to being a pure shear mode of vibration. The fact that it is not exactly a pure mode implies that, when used as a transducer, this cut will excite a small amount of longitudinal wave motion in addition to the main shear wave. If the longitudinal wave amplitude were large this could be objectionable in some applications. However, since the angle of the particle displacement is only 1.7° from the plane of the plate, the longitudinal mode excitation is in this case negligible for practical purposes. For known transducer applications there are two basically different useful orientations: one with the length axis perpendicular to the particle displacement vector, a (zxl) 73° cut; and one with the length axis along the direction of the particle displacement vector, a (zyw) −17° cut. The (zxl) 73° orientation is shown in FIG. 1. The (yzw) −17° orientation is shown in FIG. 2.

The 36° rotated Y-cut plate, a (zxl) −54° cut in IRE notation, is shown in FIG. 3. This crystal has zero coupling to the quasi-shear mode and an effective coupling factor of 49 percent for the quasi-longitudinal mode. The particle displacement for this mode is 3.8° from the plate normal, so that it is not quite as pure a mode of vibration as quasi-shear mode in the 163° rotated Y-cut. This implies that such a transducer would excite a small amount of shear wave motion in addition to the main longitudinal wave. However, experiments conducted by bonding transducers of this type to fused silica indicated that the shear wave signal was not observable and its amplitude was at least 40 db. down from the longitudinal mode signal.

$LiNbO_3$ plate with faces normal to the X-axis, as defined by the 1949 IRE standard, can vibrate in a pure longitudinal mode with the particle displacement along the X-axis, or in either of two pure shear modes with the particle displacement normal to the X-axis. However, an electric field applied in the thickness direction excites only the two shear modes. Furthermore, one of the shear modes, which will be called the strong shear mode, is excited much more efficiently than the other (weak) shear mode. The effective coupling constant is 68 percent for the strong shear mode and only 10 percent for the weak shear mode. Thus an X-cut $LiNbO_3$ transducer bonded to an isotropic delay medium would excite one shear wave very strongly and the other shear wave would be about 18 db. down. Since both shear waves in the isotropic material have the same velocity, the net result is a very slight elliptical polarization of the particle displacement, which is not objectionable.

The particle displacements of the two shear modes in the $LiNbO_3$ are not along the Y and Z crystal axes but are inclined to the crystal axes, the direction of displacement for the strong shear mode being 41° from the Z-axis.

There are two major types of ultrasonic delay lines using shear mode transducers and both of these types of delay lines require controlling the direction of the particle displacement vector. Polygon delay lines require that the particle displacement vector lie in the planes of incidence and reflection for a transverse wave reflecting from a facet. This, in turn, requires that the displacement vector be normal to the long direction of a rectangular plate. Hence in the IRE notation, the required plate is an (xyt) 41° cut. This crystal is shown in FIG. 4. The other type of line is the strip or plate delay line in which the transducers are again rectangular plates with the length usually five or more times the height. For this type of delay line, the particle displacement vector must be parallel to the major surfaces of the delay medium; consequently, along the length direction of the transducer. Again according to the IRE notation, the required plate is an (xyt) −49° cut. This plate is shown in FIG. 5.

In FIG. 6, a lithium niobate crystal, oriented as in one of FIGS. 1 to 5, is provided with electrodes 2 and 3, which may be deposited, plated, etc. in accordance with any suitable technique. Such electrodes may cover the broad crystal faces as shown or may be of lesser area to minimize unwanted coupling. Electrical connection to the electrodes is made by means of leads 4 and 5. The transducer of this figure may serve as a resonator, for example in performing the function of a filter or frequency standard, or it may be part of a larger device such as a delay line.

The device of FIG. 7 is a conventional delay line incorporating a transducer 10 which, like the device of FIG. 6, is made

up of a plate **11** of $LiNbO_3$, together with its associated electrodes **12** and **13**. Electrical connection is made by means of leads **14** and **15** connected to a signal source not shown. The elastic wave produced by the electrical signal is then launched in the acoustic medium **16**, which may be made of silica, glass, metal, or any other suitable material. For certain uses, it is desirable to use $LiNbO_3$ for this member also, it having been observed that this material shows unusually low loss particularly for frequencies above 100 mHz. Upon reaching the end of acoustic member **16**, the elastic wave is reconverted into an electromagnetic signal in transducer plate **21**, and this signal is detected by means of circuitry including electrodes **22** and **23**, together with wire leads **24** and **25**.

It should be stressed that the angle of rotation specified is critical and should not be varied by more than ±3°. Deviations greater than this result in deleterious effects on the resonator characteristics such as a reduction in the coupling efficiency and an increase in unwanted resonances.

The foregoing orientations have been consistently described as applied to a plate structure, and it is this configuration that is of concern in most transducers. For these purposes, a plate is generally about a half wavelength thick for the center frequency, that is of the order of millimeters or less. The large dimensions are generally determined on the basis of good device design, such as desired and/or permitted electrode resistance, capacitance, etc. It is reasonable to assume that transducer plates have large dimensions, at least five times the thickness dimension.

The invention has been described very briefly in terms of a small number of embodiments. The composition itself and acceptable techniques for preparing the composition are sufficiently well known so that detailed discussion is unnecessary. Fundamentally, the invention depends upon the finding that the particular orientation described results in an optimization of the properties disclosed. Minor modifications made in the composition, due either to accidental inclusions or responsive to a desire to alter properties such as temperature dependence, conductivity, absorption, growth, etc. do not alter the inventive finding. Accordingly, the preferred orientation is considered to apply so long as at least 99 percent by weight of the composition is $LiNbO_3$. Similarly, representation of the vast family of suitable transducer structures by the small number of examples set forth is not intended to limit the invention.

While the devices described have utilized crystal sections having two plane parallel surfaces each corresponding with the rotated orientation of the invention, other structures known to those skilled in the art may advantageously utilize the noted orientations. For example, it is common in the resonator art to contour one or both of the major faces so as to restrict the motion to a desired portion of the plate. This has been accomplished by tapering the surface of one or both faces away from the plateau or, in the extreme, by use of one or two convex surfaces. Still another approach, sometimes referred to as mode trapping, utilizes thickened electrodes affixed only to the desired portion of the plate. The effect of this configuration is to restrict the motion to that portion of the crystal lying between electrodes. Beveling of a resonator plate to reduce unwanted resonances is also practice. Accordingly, to benefit from the inventive teaching it is necessary only that those surface portions of the major faces associated with the motion be oriented as specified. The annexed claims are to be so construed.

Various additional modifications and extensions of this invention will become apparent to those skilled in the art. All such variations and deviations which basically rely on the teaching through which this invention has advanced the art are properly considered within the spirit and scope of this invention.

What we claim is:

1. A single crystal plate of lithium niobate having a crystal orientation selected from the following: (*yzw*) −17° (±3°), (*zxl*) −54° (±3°), (*xyt*) 41° (±3°), (*xyt*) −49° (±3°).

2. The single crystal plate of claim 1 having a (*yzw*) −17° (±3°) orientation.

3. The single crystal plate of claim 1 having a (*zxl*) −54° (±3°) orientation.

4. The single crystal plate of claim 1 having a (*xyt*) 41° (±3°) orientation.

5. The single crystal plate of claim 1 having a (*xyt*) −49° (±3°) orientation.

6. A crystal in accordance with claim 1 in combination with means for impressing an electric field across the thickness of the crystal plate.

7. An ultrasonic device comprising a crystal in accordance with claim 1, means for impressing an electric field across the thickness, and an ultrasonic wave transmission medium in association with the crystal so that elastic waves generated by said crystal propagate through the transmission medium.