TEMPERATURE AND COUPLING BEHAVIOR OF RESONATORS AND TRANSDUCERS OF LITHIUM TETRABORATE DRIVEN BY LATERAL AND THICKNESS FIELDS

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TEMPERATURE AND COUPLING BEHAVIOR OF RESONATORS AND TRANSDUCERS OF LITHIUM TETRABORATE DRIVEN BY LATERAL AND THICKNESS FIELDS (U)

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Lithium tetraborate is a tetragonal material of considerable promise for signal processing, transducer, and frequency control applications. It exhibits piezoelectric coupling values that fall between those of lithium niobate and quartz, but possesses orientations for which the temperature coefficient of frequency or delay time is zero for both bulk and surface acoustic waves.

Calculations have previously been made for rotated y-cut, bulk wave plates, including the regions where the quasi-extensional and quasi-shear thickness modes have zero temperature coefficients of frequency. In this report we extend the calculations to doubly rotated bulk wave resonators, and compute the coupling factors for the three simple thickness modes driven by [TE] and lateral [LE] quasistatic electric fields as a function of the orientation angles phi and theta, and the direction of the applied lateral field psi. Because of the temperature coefficients of the piezoelectric coupling factors, the temperature coefficient (contd)
19. ABSTRACT (contd)

of a resonator will depend not only upon orientation, but also upon harmonic number and location of the resonator operating point on the immittance circle.

It is found that two unique orientations exist in lithium tetraborate for which plate resonators have zero temperature coefficients of frequency of both first- and second-order with high values of piezo coupling factor. One cut has this favorable behavior in its thickness-stretch mode, while the other possesses it for its slow thickness-shear mode.
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INTRODUCTION

Lithium tetraborate (LBO) is a tetragonal material in crystal class 4mm ($C_{4v}$). As such it possesses a single 4-fold polar axis, and four symmetry planes containing the 4-fold axis; consequently, there are 6 independent linear elastic constants, three independent linear piezoelectric constants, and two independent linear dielectric constants.

The primitive region is 1/8th of a hemisphere, which we comprise as the angle ranges $(yxwl)\phi/\theta$, with $0 \leq \phi \leq \pi/4$ and $0 \leq \theta \leq \pi/2$. As a consequence of its symmetry, LBO is

- Pyroelectric
- Optically uniaxial (LBO is negative)
- Piezoelectric
- Not enantiomorphic (no twinning)
- Nonferroelectric (poling not required)

Particularizing to the substance lithium tetraborate (LBO), we find from the literature [1]-[26], [30]-[32], the following specific properties and virtues:

**Properties of Li$_2$B$_4$O$_7$ = Li$_2$O·2B$_2$O$_3$**

- Congruently melting phase in the lithium oxide-boron oxide system; transparent and colorless.
- Low melting point: 917°C.
- Czochralski growth, Pt crucibles, diameters > 50 mm along [100], [001], or [110]; sensitive to thermal shock (cooling).
- Lattice spacings: $a = b = 9.479 \, \text{Å}$, $c = 10.280 \, \text{Å}$.
- Mohs hardness = 6 (between LiTaO$_3$ and quartz = 7).
- Low density = 2451 kg/m$^3$, but acoustic velocities only slightly greater than those in LiNbO$_3$ and LiTaO$_3$.
- Solubility: 1) dissolves rapidly in acids, slowly in bases. 2) hot water used as etchant. 3) insolvent in organic "solvents."
- Relatively high piezocoupling $k$ and $k$ values.
- Surface acoustic wave (SAW) reflectivity per stripe > 5 times that for LiNbO$_3$, LiaO$_3$, and quartz, leading to miniaturization.
- Zero temperature coefficients of frequency and time delay for BAW and SAW.

DETERMINATION OF CONSTANTS

The elastic, piezoelectric, and dielectric constants of 4mm crystals may be determined from the simple thickness modes of thin plates driven by thickness excitation [TE] and lateral excitation [LE].

Orientation (yx); Y-cut = X-cut
[TE]: pure shear along $X_3$
$c_{44}^E$, $e_{15}$, $e_{11}^S$

[LE]: pure stretch along $X_2$, driven by $X_3$
field
$c_{11}^E$, $e_{31}$

Orientation (zx); Z-cut

[TE]: pure stretch along $X_3$
$c_{33}^E$, $e_{33}$, $e_{33}^S$

Orientation (yx1)$^\theta$; rotated Y-cut

[TE]: coupled shear-stretch
$c_{13}^E$

[LE]: pure shear along $X_1$, driven by $X_1$
field
$c_{66}^E$

Orientation (yxw)$^\psi$

[LE]: coupled shear-stretch, field along
$X_1$; $X_1$, $X_2$ motion
$c_{12}^E$

**COMPUTATIONAL SCHEME**

Input data are taken from Ref. [19], and used as follows:

- $s^E$, $d$, $e^T$ are converted to $c^E$, $e$, $e^S$.
- $c^E$, $e$, $e^S$, density, and thickness are given at reference temperature $T_o = 25^\circ C$.
- First- and second-order temperature coefficients TC(1) and TC(2) are used to compute $c^E$, etc., at two other temperatures, $T_c$ and $T_h$.
- For assumed angles $\phi$, $\theta$, and $\psi$, the conventional eigenvalue problem is solved to yield $N_m$, $k_m$, $k_m(\psi)$, etc., for each temperature, $T_c$, $T_o$, and $T_h$.
- TC(1) and TC(2) of $f_R$, $f_A$, etc., are computed for each mode, harmonic, and excitation type; for further details, see Refs. [27]-[29].

**FREQUENCY CONSTANTS AND COUPLING FACTORS**

The frequency constants, $N_m$, [TE] coupling factors, $k$, and [LE] coupling factors, $k(\psi)$, for (yxw)$^\phi$=0°(15°)45°/0 cuts having applied field direction $\psi = 0°(30°)90°$, are given in Figs. 1 to 24, respectively.
TEMPERATURE COEFFICIENTS

The first- and second-order temperature coefficients of frequency, \( TC(1) \) and \( TC(2) \), and the loci of \( TC(1)=0 \) and \( TC(2)=0 \), for \( M = 1, 3, \) and \( \infty \), for [TE] \((yxwl)\phi=0^\circ/\theta\) plates are given, respectively, for the "a" mode in Figs. 25 to 28, for the "b" mode in Figs. 29 to 32, and for the "c" mode in Figs. 33 to 36.

The first- and second-order temperature coefficients of frequency, \( TC(1) \) and \( TC(2) \), and the loci of \( TC(1)=0 \) and \( TC(2)=0 \), for mode "a", \( \psi=0^\circ(30^\circ)90^\circ \), for [LE] \((yxwl)\phi=0^\circ/\theta\) plates are given, respectively, for \( M=1 \) in Figs. 37 to 40, for \( M=3 \) in Figs. 41 to 44, and for \( M=\infty \) in Figs. 45 to 48.

The first- and second-order temperature coefficients of frequency, \( TC(1) \) and \( TC(2) \), and the loci of \( TC(1)=0 \) and \( TC(2)=0 \), for mode "b", \( \psi=0^\circ(30^\circ)90^\circ \), for [LE] \((yxwl)\phi=0^\circ/\theta\) plates are given, respectively, for \( M=1 \) in Figs. 49 to 52, for \( M=3 \) in Figs. 53 to 56, and for \( M=\infty \) in Figs. 57 to 60.

The first- and second-order temperature coefficients of frequency, \( TC(1) \) and \( TC(2) \), and the loci of \( TC(1)=0 \) and \( TC(2)=0 \), for mode "c", \( \psi=0^\circ(30^\circ)90^\circ \), for [LE] \((yxwl)\phi=0^\circ/\theta\) plates are given, respectively, for \( M=1 \) in Figs. 61 to 64, for \( M=3 \) in Figs. 65 to 68, and for \( M=\infty \) in Figs. 69 to 72.

COMPENSATED, DOUBLY ROTATED CUTS

Superposition of Figs. 27 and 28 discloses that a unique doubly rotated "a" mode orientation in LBO exists for which \( TC(1)=TC(2)=0 \). It occurs for \( \phi/\theta \approx 40^\circ/33^\circ \) at the fundamental harmonic, driven in [TE]. In a plate resonator or transducer cut at this orientation, both \( TC(1) \) and \( TC(2) \) are zero. This means that the first surviving temperature coefficient will be \( TC(3) \); i.e., the frequency-temperature curve will be cubic in nature, like that of the AT and SC cuts of quartz, and the overall excursions in frequency over a wide temperature range will be small. The corresponding \( N_a \) and \( k_a \) values may be read approximately from the graphs in Figs. 19 and 20, respectively. The frequency constant \( N_a \) is nearly a maximum when \( \theta \approx 33^\circ \), and the piezocoupling factor \( k_a \) is approximately 20%.

Superposition of Figs. 35 and 36 discloses that a unique doubly rotated "c" mode orientation in LBO also exists for which \( TC(1)=TC(2)=0 \). It occurs for \( \phi/\theta \approx 19^\circ/56^\circ \) at the fundamental harmonic, driven in [TE]. In a plate resonator or transducer cut at this orientation, both \( TC(1) \) and \( TC(2) \) are likewise zero. This again means that the first surviving temperature coefficient will be \( TC(3) \); i.e., the frequency-temperature curve will be cubic in nature, like that of the AT and SC cuts of quartz, and the overall excursions in frequency over a wide temperature range will be small. The corresponding \( N_a \) and \( k_a \) values may be read approximately from the graphs in Figs. 7 and 8, respectively. The frequency constant \( N_a \) is nearly a minimum when \( \theta \approx 56^\circ \), and the piezocoupling factor \( k_a \) is approximately 27%. 
REFERENCES


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$\phi = +45.000$

$\psi = +0.000$
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\[ \text{Li}_2\text{B}_4\text{O}_7 \]
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