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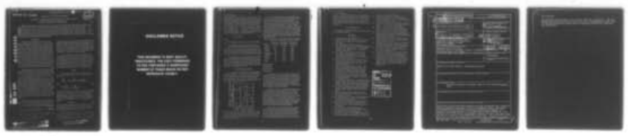

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THE SURFACE WAVE PROPERTIES OF $LiIO_3$*

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ABSTRACT. The surface acoustic wave (SAW) properties of $LiIO_3$ are theoretically studied in order to evaluate its potential for use in related SAW devices. The surface wave properties were obtained by solving the coupled electromagnetic and acoustic wave equations subject to the appropriate boundary conditions. The variation of the SAW velocity, piezoelectric coupling and power flow angle were obtained as a function of crystallographic orientation. $LiIO_3$ was found to have more than 1.5 times the piezoelectric coupling of $LiNbO_3$, relatively low power flow angle and SAW velocities in the range of 1900 m/sec to 2300 m/sec. The high piezoelectric coupling occurred for Z-cut $LiIO_3$ and was independent of angle. The low SAW velocity and high coupling make this material attractive for long delay line applications.

Introduction

In the last ten years[1] there has been a large amount of work in the study of surface acoustic wave (SAW) devices and their application in microwave engineering. A rather large number of piezoelectric materials exist in nature, however, only a relatively few have been examined in detail for possible SAW applications. There are several important properties which one can look for in a candidate material which might prove to be important in a device application. Some of these properties are (i) high piezoelectric coupling, (ii) temperature compensated crystallographic cuts for which the temperature coefficient of the transit time is zero, (iii) low loss in the surface acoustic wave, (iv) very low or very high SAW velocities, and (v) low power flow angle for the SAW. Depending upon the application of the SAW device, one or more of the above criteria should be satisfied for the piezoelectric material.

Some piezoelectric materials have been studied[2,3] in order to determine their possible usefulness in SAW devices. However, only a few materials satisfy one or more of the above criteria. $LiNbO_3$[4] is one of the most commonly used materials and exhibits the highest piezoelectric coupling. This material, however, possesses a high temperature coefficient of delay. Only quartz and TeO_2 possess temperature compensated cuts. For applications requiring temperature stability, such as SAW encoders and decoders[5], quartz is used. However, the piezoelectric coupling of quartz is about 1/30th of the coupling in $LiNbO_3$ while the coupling of TeO_2 is about 1/5th the coupling in quartz. Composite structures have been used[6,7] to satisfy the temperature compensation criterion but the fabrication problems are more involved. For long delay lines bismuth germanium oxide[8] is used due to its relatively low SAW velocity. The coupling in this material is however one third that of $LiNbO_3$.

It is the purpose of the present paper to theoretically calculate the surface wave velocity, the piezoelectric coupling and the power flow angle for $LiIO_3$ in many crystallographic directions. This material crystallizes in the hexagonal structure[9-11] and belongs to the point group 6. The motivation for studying the SAW properties was due to the extremely large piezoelectric effect observed[12-18] in this material and hence the possible use of this material in related SAW devices. Preliminary experimental measurements and theoretical calculations have been performed[19-21] on $LiIO_3$. These results indicate that this material has both large piezoelectric coupling and a relatively low SAW velocity.

In the present work the SAW properties are obtained by solving the coupled electromagnetic and acoustic wave equations subject to the appropriate boundary conditions. In particular the surface wave velocity, the piezoelectric coupling and the power flow angle are calculated as a function of angle for all the standard crystallographic cuts. $LiIO_3$ is then compared to other common SAW materials and a possible application of this material in a related SAW device is discussed.

Theory

In a piezoelectric medium the coupled electromagnetic and acoustic wave equations may be written as,

$$\rho \frac{\partial^2 u_j}{\partial t^2} - C_{ijk\ell}\frac{\partial^2 u_k}{\partial x_i \partial x_\ell} - e_{kij}\frac{\partial^2 \phi}{\partial x_k \partial x_i} = 0$$

and (1)

$$e_{ik\ell}\frac{\partial^2 u_k}{\partial x_i \partial x_\ell} - \epsilon_{ik}\frac{\partial^2 \phi}{\partial x_k \partial x_i} = 0$$

where ρ is the density; $i, j, k, \ell = 1, 2, 3$; u_i, the displacement components; x_i, the rectangular coördinate; $C_{ijk\ell}$, the elastic constant tensor; e_{kij}, the piezoelectric tensor; ϵ_{ik}, the dielectric permittivity tensor; and ϕ, the scalar potential. In the air above the piezoelectric medium the potential satisfies Laplace's equation,

$$\nabla^2 \phi = 0 \quad . \tag{2}$$

If equations (1) and (2) are solved simultaneously subject to the conditions that the stress vanishes on the surface and the flux density is continuous across the boundary the SAW velocity may be obtained.

A measure of the piezoelectric coupling between the electromagnetic wave and acoustic wave can be obtained[2] by calculating the change in velocity between a surface wave propagating on a piezoelectric substrate bounded by a vacuum and a surface wave propagating on

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a piezoelectric substrate with a massless infinitely thin conductor on the surface. This may be reasoned as follows. If there was no change in the velocity, there would be no interaction between the conductor and the surface wave. It is then concluded that an electrode configuration having tangential electric fields at the surface would have little effect in surface wave generation. However, if the velocity change was significant the electrode-surface wave interaction should be greater. Mathematically, the piezoelectric coupling is measured in terms of velocity change as follows,

$$\frac{\Delta v}{v} = \frac{v - v_o}{v} , \qquad (3)$$

where

v = velocity of a surface wave on a free surface

and

v_o = velocity of the surface wave with an infinitely thin massless conductor on the surface.

Obviously, a material which has a high value of $\Delta v/v$ relative to other piezoelectric materials indicates a significant interaction between the conductor and the surface wave and hence substantial piezoelectric coupling.

The power flow angle may be obtained by evaluating the complex mechanical and electrical power components. The corresponding angle between the average electromechanical power flow and the direction of propagation is defined as the power flow angle. Both the power flow angle and its rate of change along a crystallographic cut should be quite low.

Results and Discussions

The surface wave velocity, the piezoelectric coupling and the power flow angle were calculated by the computer program developed[3] for $LiGaO_2$. The experimental data for the elastic constants and the piezoelectric constants were obtained from the work of Haussühl[18] while the dielectric constants were obtained from the work of Warner et al.[17]

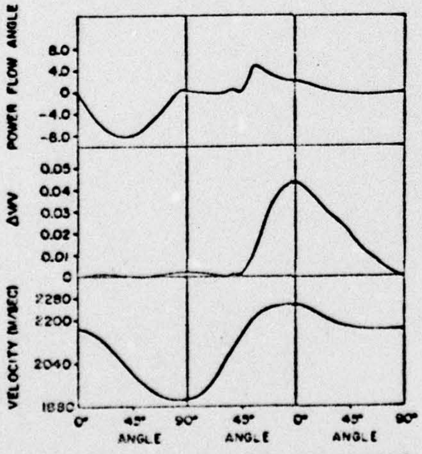

Figure 1. The variation of the SAW velocity, $\Delta v/v$ and the power flow angle for standard crystallographic cuts in $LiIO_3$. Z cut occurs at X and Y axis cylinder, 0°, Z-axis boule at X and Y cut, 90° and Z-axis cylinder at X and Y-axis boule, 90°.

The variation of the surface wave velocity, the piezoelectric coupling and the power flow angle is presented for six standard crystallographic cuts in Figure 1. The cuts have been connected so that there is a continuous variation for the quantities of interest. The values for the Z type cuts, i.e., Z-cut, Z-axis boule, and Z-axis cylinder are not shown but may be deduced from Figure 1. Because of the hexagonal symmetry of the $LiIO_3$ lattice there is no variation in SAW properties over any of these cuts. The values for the SAW properties of Z-cut are those of X and Y-axis cylinder at 0°, for Z-axis boule they are those of X and Y-cut at 90° while for Z-axis cylinder they are those of X and Y-axis boule at 90°.

Table 1 Maximum $\Delta v/v$ and maximum and minimum SAW velocities for various piezoelectric materials.

Material	Maximum $\Delta v/v$ ($\times 10^{-2}$)	Minimum Vel (M/sec)	Maximum Vel (M/sec)
$LiIO_3$[a]	4.34	1904	2258
$LiNbO_3$[b]	2.8	3318	4000
$LiTaO_3$[b]	.87	3110	3390
$Bi_{12}GeO_{20}$[c]	.80	1623	1834
$LiGaO_2$[d]	.66	3173	3475
Quartz[b]	.11	3175	3840
TeO_2[b]	.02	825	2028 .

[a] present work

[b] Reference 2

[c] Reference 22

[d] Reference 3

The most attractive cut in $LiIO_3$ for possible SAW applications is Z-cut. The piezoelectric coupling reaches its maximum value and remains constant throughout the cut. The power flow angle is not too high and its corresponding rate of change along this cut is zero. Even though the SAW velocity is quite large for Z-cut in comparison to other cuts in $LiIO_3$, this velocity is still rather low compared to the SAW velocities of many of the commonly used SAW materials.

$LiIO_3$ is compared to some of the other SAW materials in Table 1. In particular the minimum and maximum SAW velocities and the maximum piezoelectric coupling are presented for various materials. $LiIO_3$ possesses the highest piezoelectric coupling of the materials listed. In fact its coupling is more than 1.5 times the coupling in $LiNbO_3$ which possesses the highest coupling of the commonly used SAW materials. The SAW velocities in $LiIO_3$ are quite low and only slightly higher than those occurring in $Bi_{12}GeO_{20}$ which is a material commonly used in long delay lines.

$LiIO_3$ has definite possibilities for device applications. Its high coupling plus relatively low SAW velocity make it an excellent candidate material for long delay lines. The fact that there is no variation in the surface wave properties for Z-cut $LiIO_3$ would definitely facilitate the delay line design. Further experimental work would determine the usefulness of this material for other SAW devices such as filters, resonators, directional couplers etc. One possible problem might arise in the fabrication process due to the fact that $LiIO_3$ is slightly hygroscopic. Experimental work in the measurement of surface wave properties and the design of long delay lines is currently under investigation.

Acknowledgements

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