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NEW LOW LOSS HIGH COUPLING MODE UP TO 1 GHZ ON LINBO3,(U)

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NEW LOW LOSS HIGH COUPLING MODE UP TO 1 GHz on $LiNbO_3$

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ABSTRACT Experimental measurements of 345 MHz surface acoustic waves propagating along the X-axis of Z-cut lithium niobate have revealed the existence of a low-loss, high-coupling mode whose insertion loss is less than the Rayleigh-type surface acoustic wave. When the double electrode of quarter-wavelength transducers were excited at the third overtone at 1035 MHz, the insertion loss of this mode was about 10 dB less than that of the SAW. The experimentally observed velocity of this mode was 4375 m/sec, considerably higher than the metalized SAW velocy of 3800 m/sec, but in excellent agreement with the theoretical calculated metalized pseudo SAW velocity. The experimentally determined coupling ($\Delta v/v$) for this mode is almost a factor of three times that of the SAW. This volume mode is theoretically explained in terms of a combination of plate modes. A potential applicationof this new mode is in low-loss, broadband signal processing devices.

Introduction

It is well known that when a surface acoustic wave (SAW) is excited several spurious bulk type modes are simultaneously excited. These spurious modes were initially considered to be of no value and efforts were made to minimize their effect.[1] These modes not only sap energy from the input signal but also cause unwanted responses to appear at the output of the SAW device. Recently, however there has been some effort to try to use spurious bulk type modes for useful purposes. One such bulk type mode which has received some attention is the surface skimming mode.[2]

It is the purpose of the present paper to investigate a new low-loss, high coupling volume or bulk mode on Z-cut X-propagating (ZX) lithium niobate. The velocity of this new mode is significantly larger than the SAW velocity and in good agreement with the theoretically determined metalized pseudo SAW velocity. The ratio of the estimated electromagnetic to acoustic coupling ($\Delta v/v$) of this volume mode to that of the SAW mode, as determined from the input resistance, is $2.6 \pm .2$. This mode which occurs in a cut for which both a SAW and a pseudo SAW may exist is theoretically explained in terms of a combination of plate modes.

Theory

The SAW properties of $LiNbO_3$ were obtained by solving the coupled electromagnetic and acoustic wave equations subject to the appropriate boundary conditions. The variation of the SAW velocity, pseudo-SAW velocity, temperature coefficient of delay, $\Delta v/v$, power flow angle and attenuation for the pseudo SAW for a range of $\pm$ 30° about the Z-cut X-propagating direction is presented in Figure 1. A summary of the calculated velocities for surface and bulk type waves is given in Table 1.

The pseudo SAW mode radiates its energy into a shear wave whose phase angle θ (See Fig. 2) is determined by

$$\cos\theta = v_{SH}/v_{PSAW} \qquad (1)$$

where

v_{SH} = velocity of the slow shear wave

and

v_{PSAW} = velocity of the pseudo SAW.

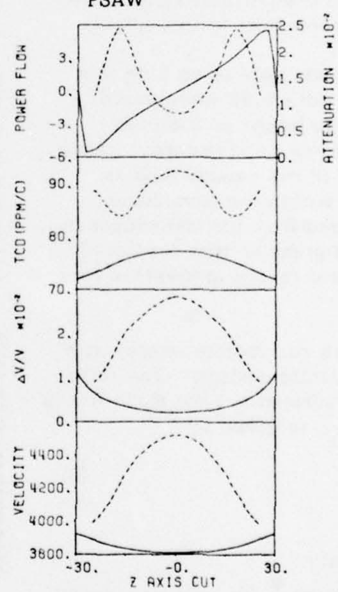

Fig. 1 The variation of SAW velocity, pseudo SAW velocity, TCD, $\Delta v/v$, power flow angle and attenuation for the pseudo SAW for a range of $\pm$ 30° about Z-cut X-propagating $LiNbO_3$. Solid line: properties associated with the SAW. Dotted line properties associated with pseudo-SAW.

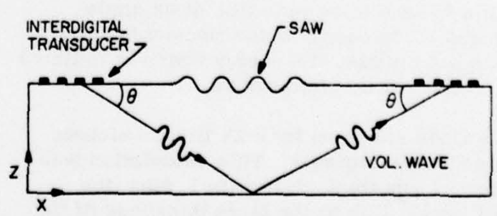

Fig. 2 Volume wave propagation path.

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Table 1. Calculated velocity and $\Delta v/v$ for various surface and bulk modes in Z-cut X propagating $LiNbO_3$

Wave	θ(See Fig. 2)	Velocity (m/sec) Free Surface	Metalized	$\Delta v/v$
SAW	0^o	3808	3800	$2.1x10^{-3}$
Pseudo SAW	0^o	4517	4389	$2.8x10^{-2}$
Slow Shear	0^o	4079		
	25^o	3960		
	30^o	3925		

For a metalized surface $\theta = 25^o$ and for a free surface $\theta = 30^o$.

The attenuation associated with the pseudo SAW is

$$Att = \exp(-\frac{2\pi}{\lambda} \gamma x), \tag{2a}$$

where x is the propagation distance and λ is the wavelength. Substituting the computed value of $\gamma = 0.00825$ in equation 2a one obtains,

$$Att = 0.45\ x/\lambda\ (dB). \tag{2b}$$

The wavelength of the pseudo SAW whose velocity on a free surface is 4517 m/sec is 11.4 μm at 398 MHz. This yields an attenuation of 200 dB for a propagation distance of 5 mm. Hence the pseudo SAW is too lossy to propagate from the input transducer to the output.

The attenuation of the pseudo SAW is so high that it loses half of its energy in only 6.66 wavelengths, which is much shorter than the length of the interdigital transducers used in these experiments. Hence, essentially all of the energy of the pseudo SAW is radiated into a volume wave within the transducer. The effective $\Delta v/v$ as measured from the transducer input impedance will not be as great as that predicted from the theory, as transducer theory ignores this loss of the propagating wave.

All interdigital transducers can radiate energy at a phase angle θ into a semi infinite medium. The ratio of the frequency, "f", of a radiated volume mode to the SAW resonance frequency, f_s, is given by

$$f/f_s = v(\theta)/v_{SAW} \cos\theta, \tag{3}$$

where

$v(\theta)$ = volume wave velocity.

The presence of the pseudo SAW in ZX lithium niobate enhances this volume wave radiation at an angle between 25 and 30 degrees. If the medium is not semi-infinite but a plate, the energy which is radiated into the bulk will set up plate modes.

The plate mode spectrum for a ZX lithium niobate plate is presented in Figure 3. This calculation was performed for a 1 mm thick plate with 1.4μm line width transducers. Due to the large thickness of the plate in wave lengths there are a large number of allowed plate modes very close to one another. It is interesting to note that the plate mode coupling peaks at approximately the same point as the pseudo SAW velocity. This is elaborated upon later.

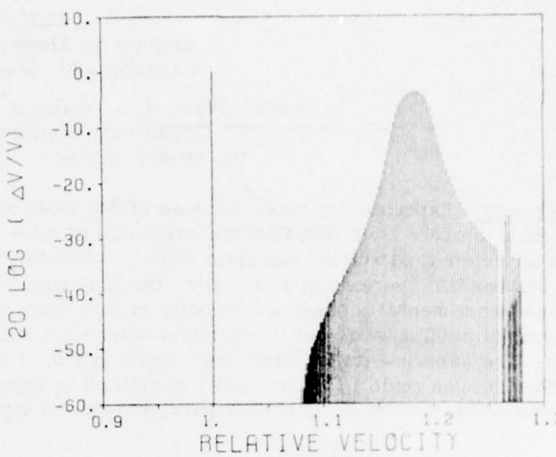

Fig. 3 Plate mode spectrum for a 1 mm thick ZX $LiNbO_3$ plate with 1.4 μm line width.

Experiment

Experiments were performed with a number of different double-electrode interdigital transducers all of which were unapodized. The Z-cut, X-propagating lithium niobate slabs had thicknesses of 1 mm and 4 mm and the bottom surfaces were rough-ground.

Figure 4 shows the insertion loss as a function of frequency for waves generated on a 1 mm thick ZX lithium niobate plate and detected by 1.4μm linewidth double-electrode transducers. The insertion loss of the volume wave at 398 MHz is less than that of the SAW at 345 MHz. The third overtone of the SAW mode occurs at 1031 MHz together with the third overtone of the volume mode at 1195 MHz. Closely associated with the low insertion loss of the volume mode is its more highly coupled resonance of the input impedance.

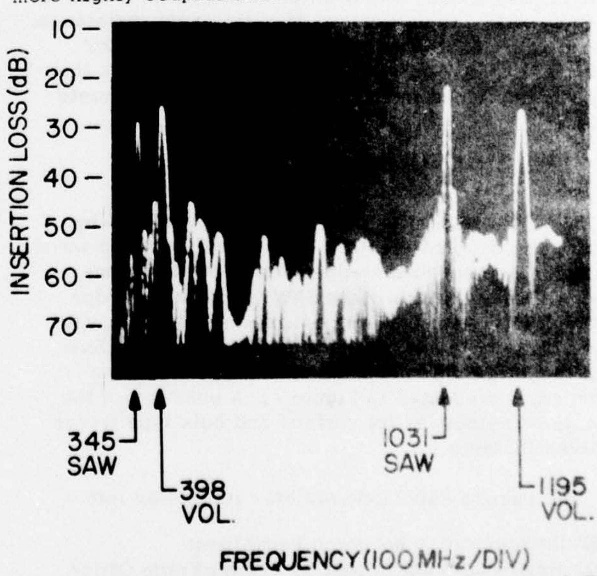

Fig. 4 Insertion loss vs. frequency for a 1 mm thick Z-cut, X-propagating $LiNbO_3$ plate.

In Figure 5 the volume mode resonances at 401 and 1212 MHz are more highly coupled than the SAW resonances at 345 and 1030 MHz. The ratio of the volume mode ($\Delta v/v$) to that of the surface acoustic wave mode is 2.6 ± 0.2, as computed from the input resistance.

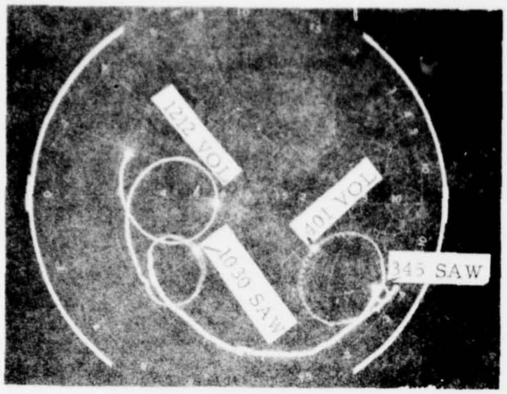

Fig. 5 Input impedance for a double electrode transducer (136, 1.4µm lines which were .132 mm long) used in Fig. 4.

In Table II the ratio of the volume wave resonance to the SAW resonance frequency, f_v/f_{SAW}, for various transducer geometries is compared to the theoretical v_{PSAW}/v_{SAW} ratio for metalized and unmetalized surfaces.

Table II. Comparison of the volume wave resonance frequency to SAW resonance frequency, f_v/f_{SAW}, for various transducer geometries to the theoretical v_{PSAW}/v_{SAW} ratio for metalized and unmetalized surfaces

Theory v_{PSAW}/v_{SAW}		Experiment f_v/f_{SAW}	Transducer Geometry
Metalized	Unmetalized	1.16	1.4µm lines, .38 mm long
1.186	1.155	1.18	1.2µm lines, 1.1 mm long

One concludes from this that the ratio of the resonance frequency is the same as the ratio of the velocity of the pseudo SAW to that of the SAW. As the transducers consist of an alternating series of metalized lines and a free surface, one might expect that the experimentally observed resonance frequency would be between the extreme cases of a completely metalized surface and a free surface, as is indeed the case. When the ratio of the distance between the transducers to the plate thickness was 5:1, the ratio of the resonance frequencies measured from the insertion loss and from the input impedance was the same.

The insertion loss of the volume wave was critically dependent upon the spacing between the input and output transducers. For the 4-mm-thick slab only the SAW could be observed for a transducer spacing of 1.27 cm. The volume wave resonance of the type observed in Figure 4 was more than 50 dB down. This observation eliminates the possibility of a surface skimming bulk mode, which should be observable for any transducer spacing, and establishes the validity of a volume wave which is reflected from the bottom surface, as shown in Figure 2.

A series of experiments was then performed to find the spacing between the transducer which gives the largest volume wave signal. Figure 6 illustrates both the 2 MHz-bandwidth SAW resonance at 402.6 MHz and the 7.5 MHz-bandwidth volume wave resonance at 475.5 MHz. The slab thickness was 1 mm and the distance between the 1.1-mm long transducers was 5 mm. The volume wave resonance is symmetric about the center frequency, as the transducer is centered on the maximum of the volume wave energy. When the transducer separation was reduced to 4 mm, the volume wave resonance was highly asymmetric, as only the outer edge intercepted the volume wave energy maximum. This caused an additional 10 dB of insertion loss as compared to the 5 mm spacing. Similar results were observed for the 4 mm thick slab, although the broadening of the volume wave resonance was not as marked, due to the longer propagation path. The optimum transducer spacing to slab thickness ratio is 5:1. These results show that the volume wave radiation is strongly enhanced by the pseudo SAW radiation at a phase angle of 25 to 30 degrees. It was also noted that the bandwidth increased as the transducer length was increased.

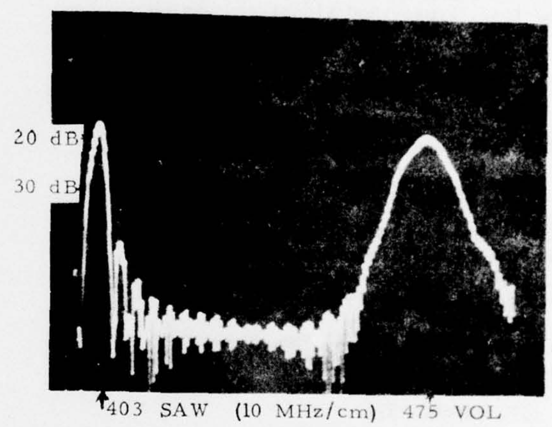

Fig. 6 Insertion loss versus frequency for a 1 mm thick ZX $LiNbO_3$ plate. The transducer had 226 double electrode lines, 1.2 µm wide and .5 mm long.

Time delay measurements were made with a pulse whose width was about one-half microsecond. The time delay of the volume wave was the same as the SAW for the optimum 5:1 spacing-to-thickness ratio. This confirms the condition of Eq (1) for the existence of a leaky-volume or pseudo SAW. Time delay and spacing predictions from Eq (3) and from the geometry illustrated in Figure 2 were in reasonable agreement with experimental observations. When an absorber was placed on the surface of the crystal, the SAW was completely absorbed, while the volume wave was unaffected. When the theoretically computed value of $\Delta v/v = 0.0021$ was used together with the measured value of the transducer capacitance to compute the acoustic radiation resistance, this agreed with the experimentally measured value to within an uncertainty of about 15 percent.

Conclusions

A new low-loss volume wave mode has been investigated on Z-cut, X-propagating lithium niobate. The optimum transducer spacing-to-thickness ratio for this volume mode is 5:1, a result consistent with the radiation of the bulk waves at a phase velocity angle of 25 to 30 degrees. The presence of the pseudo SAW enhances the normal volume wave radiation at phase angles between 25° and 30°. This causes the plate mode spectrum to have a coupling peak at approximately the pseudo SAW velocity. Since the coupling peak for the individual plate modes is not as high as the experimentally observed coupling of the volume modes, one is led to the conclusion that the energy radiated from the pseudo SAW into the bulk goes into more than one plate mode. The coupling to volume modes of much thinner plates than those investigated here has been computed to be greater than that of the SAW.[4]

An interesting property of this type of bulk mode generation is that the bandwidth increases in proportion to the transducer length in contrast to the opposite behavior for the SAW mode (as in Fig. 6). In order to achieve broad-bandwidth with the SAW mode, a short transducer is required, into which it is difficult to match. On the other hand, long, many-fingered transducers are easy to match into. In the present work an excellent match into the volume wave mode without the use of an inductor was obtained. Hence, a potential application of the volume wave mode is in low-loss, broad-band signal processing devices.

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References

1. R.F. Mitchell and E. Read, "Suppression of Bulk Wave Radiation from Surface Acoustic Wave Devices", IEEE Trans. Sonics and Ultrasonics Su-22, pp 264-270, July, 1975.

2. T.I. Browning and M.F. Lewis, "New Family of Bulk Acoustic Wave Devices Employing Interdigital Transducers", Electronics Letters, Vol.13, pp 128 - 130, March, 1977.

3. P.H. Carr, "The Generation and Propagation of Acoustic Surface Waves at Microwave Frequencies", IEEE Trans. Microwave Theory and Techn. MTT-17, pp 848-855, November 1969.

4. R.S. Wagers, "Plate Mode Coupling in Acoustic Surface Wave Devicer," IEEE Trans. Sonics Ultrasonics SU-32, pp 113-127, March 1976.