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TEMPERATURE COMPENSATED CUTS OF BERLINITE AND β -EUCRYPTITE FOR SAW DEVICES

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Abstract

Calculations of the surface acoustic wave (SAW) properties of berlinite (AlPO_4) and β -eucryptite ($\beta\text{-LiAlSi}_2\text{O}_6$) show that both materials are temperature compensated along both singly rotated and doubly rotated orientations.

For berlinite, several orientations combine zero electromechanical power flow angles with more than four times the piezoelectric coupling of ST cut quartz. The best singly rotated orientation is a direct analog of the ST cut of quartz. This cut has, like ST quartz, a zero electromechanical power flow angle, but the distinct advantage of more than four times the piezoelectric coupling. Even more promising are the results obtained for two doubly rotated cuts which combine all the advantages of the singly rotated cut with the added feature of better diffraction properties than ST cut quartz.

For β -eucryptite, a singly rotated orientation has a SAW velocity of 3662 m/sec and almost twice the piezoelectric coupling of ST cut quartz, but the disadvantage of an electromechanical power flow angle of 18 degrees. On the other hand, a doubly rotated orientation has a zero electromechanical power flow angle, but only half the piezoelectric coupling of ST cut quartz.

The results for berlinite show that it represents an attractive alternative to quartz for use in broad-band, low insertion loss SAW devices. The relatively low piezoelectric coupling of β -eucryptite makes it unattractive for broad-band, low insertion loss applications, but its relatively large SAW velocity indicates that it may be useful in high frequency applications.

Introduction

The desire to develop improved broad-band, low insertion loss SAW devices with temperature independent performance characteristics has resulted in a search for substrate materials that are temperature compensated and have piezoelectric coupling greater than that of ST cut quartz. A major contribution to the search for such materials has been the development of a phenomenological model¹ which explains why known materials are temperature compensated. According to that model, temperature compensated materials possess either of the following anomalous properties: (1) a positive temperature coefficient of velocity or elastic constant or (2) a negative coefficient of thermal expansion. Quartz, for example, is temperature compensated² because the temperature coefficient of C_{66} , the elastic constant for shear propagation along the Z axis, is positive¹.

Because quartz is temperature compensated, recent attention has been focused on certain quartz derivatives. Two of these materials, berlinite (AlPO_4) and β -eucryptite ($\beta\text{-LiAlSi}_2\text{O}_6$), are particularly interesting because they each satisfy one of the criteria of the above-mentioned phenomenological model. Berlinite has, like quartz, a positive temperature coefficient for C_{66} , the elastic constant for shear propagation along the Z axis. β -eucryptite, on the other hand, has a negative coefficient of thermal expansion in the direction of the hexagonal C-axis^{4,5}.

Recent calculations of the surface acoustic wave properties of berlinite and β -eucryptite have shown that both of these materials are temperature compensated

along both singly rotated and doubly rotated orientations. This paper will review the results of those calculations, consider their significance for SAW applications, and briefly compare them with results obtained with other materials being studied.

Berlinite

The procedure used to calculate surface acoustic wave properties has been described before^{6,7,8}. It requires, for the material being studied, experimental values for the elastic, piezoelectric, and dielectric constants, their respective temperature coefficients, the density, and the coefficients of thermal expansion. In the calculations reported here, the constants for berlinite were all taken from the data of Chang and Barsch³.

Initial results showed that berlinite indeed has temperature compensated cuts with more than four times the piezoelectric coupling of ST cut quartz⁶. However, none of those initially reported cuts had a zero electromechanical power flow angle, a desirable property characteristic of ST cut quartz. Subsequent calculations produced two singly rotated cuts and two doubly rotated cuts, all of which have zero electromechanical power flow angles⁷. The most promising of the singly rotated cuts is the X axis boule 80.4° cut, a direct analog of the ST cut of quartz. The two cuts are compared in Table I. Note that the piezoelectric coupling, $\Delta V/V$, of the X-axis boule 80.4° cut is more than four times as large as that of ST quartz, a distinct advantage. Other calculations have been made to investigate the behaviour of pseudo surface acoustic waves on berlinite⁹.

Table I also shows that the slope of the power flow angle, $\partial\theta/\partial\theta$, is larger for the X axis boule 80.4° cut of berlinite than it is for the ST cut of quartz. According to the theory of SAW diffraction¹⁰, this means that ST cut quartz has better diffraction properties than the X axis boule 80.4° cut of berlinite. The desire to find temperature compensated cuts of berlinite having better diffraction properties than the singly rotated 80.4° cut motivated consideration of doubly rotated cuts. In particular, the $\mu = 90.0$ plane of an orthogonal coordinate system having the three Euler angles λ , μ , and θ as its basis was carefully searched. The $\mu = 90.0$ plane was of particular interest because it contains four of the standard crystallographic cuts, including the X cut and Z axis cylinder, for which temperature compensated orientations were found earlier.

The results are shown in Figure 1. The dashed and solid curves represent, respectively, the loci of Euler angles for which the electromechanical power flow angle and the temperature coefficient of time delay are zero. As can be seen in the blown up portion of the Figure, the loci intersect in a total of twelve places throughout the plane. Because of crystal symmetry, however, only two of the points are independent, and those circled in Figure 1 are listed in Table I. Notice that while they have about the same piezoelectric coupling as the singly rotated 80.4° cut, the slopes of their power flow angles are smaller than those of either the 80.4° cut or the ST cut of quartz, giving them the added advantage of less diffraction spreading.

 β -Eucryptite

To calculate the SAW properties of β -eucryptite, coefficients of thermal expansion were obtained from

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the data of Hummel⁴ and Schulz⁵, and dielectric constants were obtained from the data of Bohm¹¹. Values for the elastic and piezoelectric constants and the density were obtained from the data of Barsch and Spear¹², which were measured on samples of β -eucryptite grown at Pennsylvania State University. Figure 2 shows the variation of SAW velocity, electromechanical power flow angle, piezoelectric coupling, and temperature coefficient of time delay for the X cut, for which a singly rotated temperature compensated orientation was found at 69°. Table I shows that although the piezoelectric coupling for this cut is almost twice as large as that of ST quartz, it has the disadvantage of an 18 degree electromechanical power flow angle.

As was done in the case of berlinite, doubly rotated cuts were considered also, and a temperature compensated cut having a zero electromechanical power flow angle was found in the $\lambda = 0.0^\circ$ plane, as shown in Figure 3. As can be seen in the Figure, the loci intersect in a total of four places throughout the plane. Again, because of crystal symmetry, only one of the points is independent, and it is listed in Table I where it can be seen that, unfortunately, the piezoelectric coupling of this doubly rotated cut is only about half as large as that of ST quartz. Perhaps the most attractive feature of this material is that it has the highest SAW velocity of all the temperature compensated materials listed in Table I, 3662 m/sec.

Other Temperature Compensated Materials

The sulfosalts are a class of materials of the form Tl_3BX_4 , where B can be V, Nb, or Ta, and X can be S or Se. Recent calculations have shown that at least two of these materials are temperature compensated with significantly larger piezoelectric coupling than berlinite^{13,14}. One particular cut of Tl_3VS_4 , for example, has four times the piezoelectric coupling of berlinite¹³. As shown in Table I, however, this cut has the disadvantage of a rather large electromechanical power flow angle, about -17 degrees. Another cut of the same material and one of Tl_3TaSe_4 , having zero electromechanical power flow angles, have also been found¹⁵. As the data in Table I shows, the piezoelectric coupling of these cuts is not as large as that of the first cut discussed, but it is still more than twice as large as that of berlinite. The table also shows that the SAW velocities of the sulfosalts are only about 1/3 as large as that of berlinite. This is a disadvantage for high frequency applications, but an advantage for long delay lines and low frequency SAW filters.

A composite material, consisting of a film of silicon dioxide on lithium tantalate, has also been shown to be temperature compensated¹⁶. This material has, as shown in Table I, a very small electromechanical power flow angle, a piezoelectric coupling of about .007, and a relatively large SAW velocity. The most attractive feature of the material is that its second order temperature coefficient of time delay is nearly an order of magnitude smaller than that of ST cut quartz. Despite these positive attributes, the composite has several drawbacks due to the SiO_2 film, including: (1) its thickness must be very accurately controlled, (2) it is very lossy at high frequencies, and (3) it is dispersive.

Conclusions

Several temperature compensated cuts of berlinite, having zero electromechanical power flow angles and more than four times the piezoelectric coupling of ST cut quartz, have been found. Even more encouraging are recent measurements of the piezoelectric strain constant d_{11} by X-ray methods which have shown that this quantity and, consequently, the piezoelectric coupling may be

20 to 30 percent larger than the previously determined values¹⁷. All these results indicate that berlinite appears to be a better substrate material than quartz, and as good quality supplies of the material become available, it will be attractive for use in broad-band, low insertion loss surface acoustic wave devices.

β -Eucryptite has also been shown to be temperature compensated, and this lends further credence to the phenomenological model which helps predict which materials may be temperature compensated. The piezoelectric coupling of β -eucryptite is relatively poor, however, and it does not appear to be as attractive for broad-band, low insertion loss applications as berlinite; however, because of its relatively large SAW velocity, it may find use in high frequency applications.

Berlinite and β -eucryptite are shown on the state-of-the-art diagram in Figure 4, along with the other materials discussed above. Clearly, the search for high coupling temperature compensated materials has produced some attractive results, and it promises to produce more. No single one of these materials is perfect for every SAW application, but together they increase the variety of choices available to the design engineer and, most importantly, they remove the need to use lithium niobate with its associated ovens for broad-band, low insertion loss devices, for which ST quartz is not adequate.

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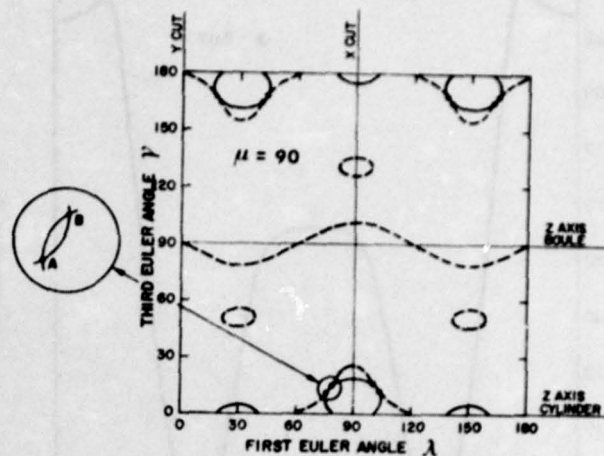
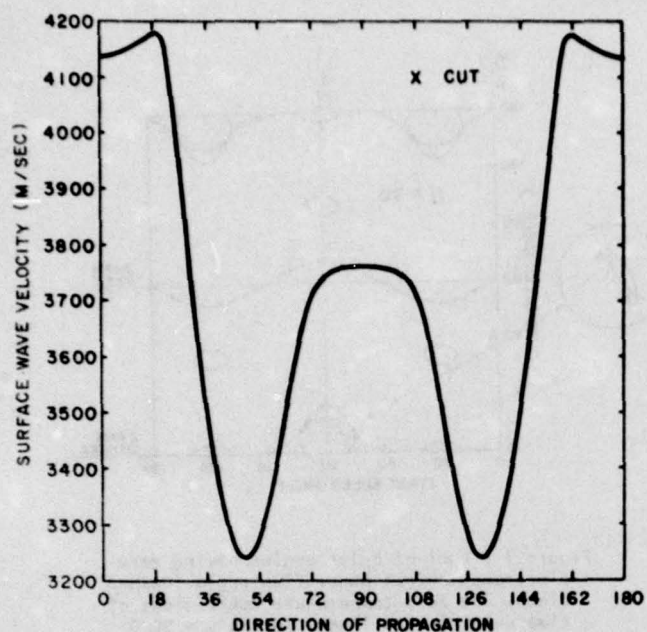


Figure 1 - Loci of Euler angles having zero electromechanical power flow angle (dashed lines) and zero temperature coefficient of time delay (solid lines) in the $\mu = 90.0$ plane of berlinite.

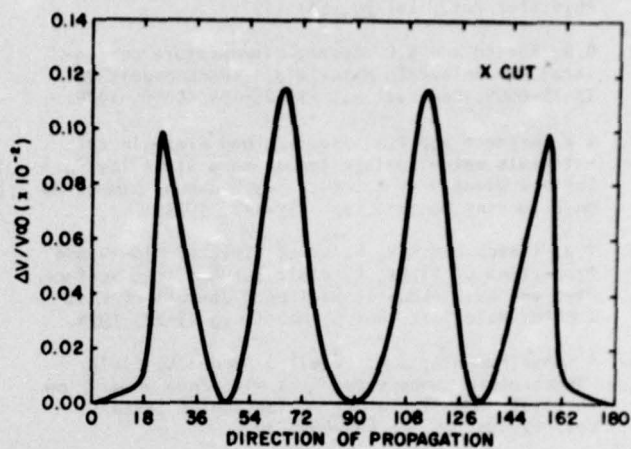
MATERIAL	ORIENTATION	EULER ANGLES λ μ θ			POWER FLOW ANGLE ϕ (DEG)	SLOPE OF POWER FLOW ANGLE $(\phi/\partial\theta)$	$\Delta v/v_{\infty}$ ($\times 10^{-2}$)	SAW VELOCITY (m/sec)
QUARTZ (SiO_2)	ST CUT	0	132.75	0	0.0	0.378	0.058	3158
BERLINITE ($AlPO_4$)	X AXIS BOULE 80.4°	0	80.4	0	0.0	0.901	0.245	2751
	DOUBLY ROTATED, A	76.8	90	11.5	0.0	0.372	0.250	2756
	DOUBLY ROTATED, B	79.7	90	15.5	0.0	0.221	0.247	2758
β -EUCRYPTITE (β - $LiAlSiO_4$)	X CUT 69°	90	90	69	18	--	0.100	3662
	DOUBLY ROTATED	0	57	62	0.0	0.32	0.035	3258
Ti_3VS_4	(110) CUT 70°	-45	90	70	-17	--	1.0	900
	(110) CYLINDER 24°	45	24	90	0.0	--	0.617	1010
Ti_3TaSe_4	(110) CYLINDER 54°	45	54	90	0.0	--	0.508	879
$SiO_2/LiTaO_3$	Y CUT, Z PROP	0	90	90	0.0	--	0.7	3455

TABLE 1. TEMPERATURE COMPENSATED CUTS OF VARIOUS MATERIALS

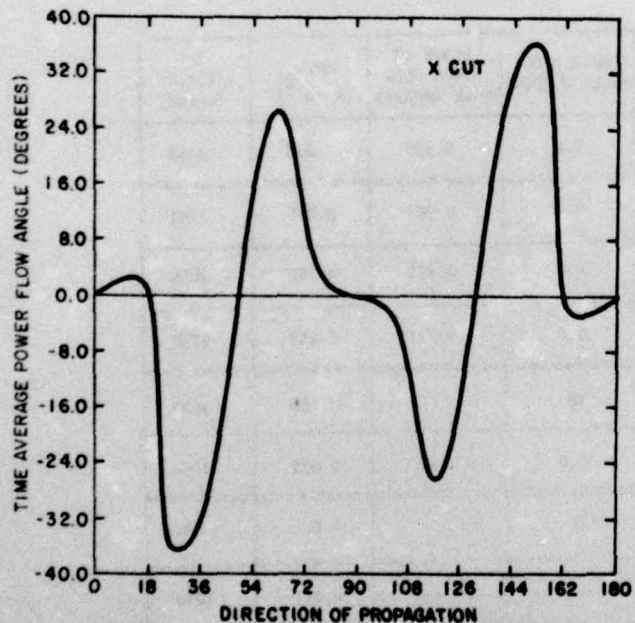
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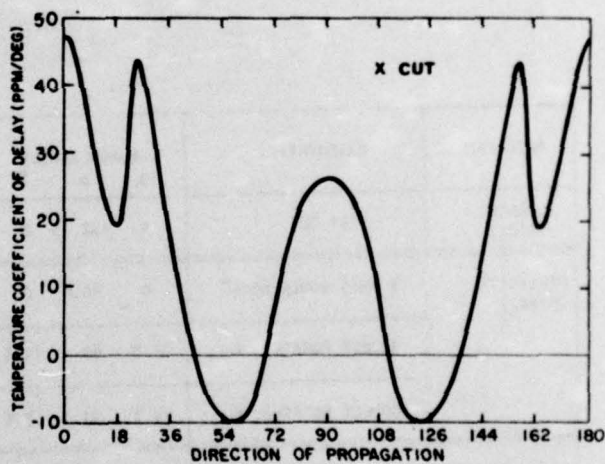
(a) SAW velocity



(c) Piezoelectric coupling



(b) Electromechanical power flow angle



(d) Temperature coefficient of time delay for X-cut β -eucryptite

Figure 2 - The variation of (a) SAW velocity, (b) electromechanical power flow angle, (c) piezoelectric coupling, and (3) temperature coefficient of time delay for X-cut β -eucryptite.

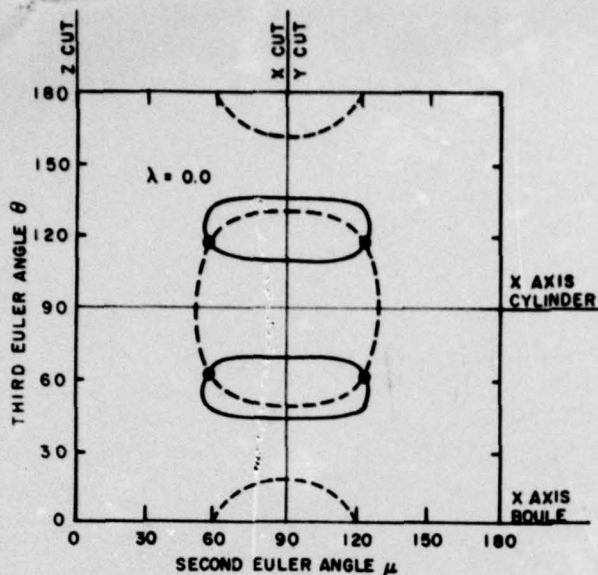


Figure 3 - Loci of Euler angles having zero electromechanical power flow angle (dashed lines) and zero temperature coefficient of time delay (solid lines) in the $\lambda = 0.0$ plane of β -eucryptite.

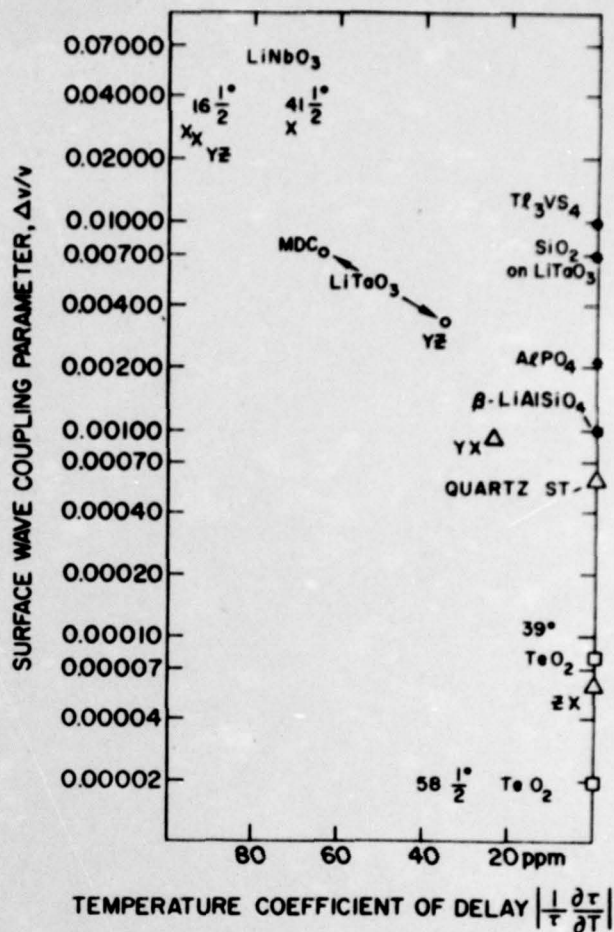


Figure 4 - Temperature coefficient of time delay versus piezoelectric coupling for various SAW materials.

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