Calculations of the surface acoustic wave (SAW) properties of berlinite (AlPO₄) and β-eucryptite (β-LiAlSi₅O₁₄) 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 broadband, low insertion loss SAW devices. The relatively low electromechanical coupling of β-eucryptite makes it unattractive for broadband, low insertion loss applications, but its relatively large SAW velocity indicates that it may be useful in high frequency applications.

To calculate the SAW properties of β-eucryptite, coefficients of thermal expansion were obtained from...
the data of Hummel$^{6}$ and Shultz$^{5}$, and dielectric constants were obtained from the data of Bohm$^{1}$. Values for the elastic and piezoelectric constants and the density were obtained from the data of Barsch and Spear$^{12}$, which were measured on samples of B-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 obtained 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 $X = 0$ 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 these points is independent, and it is listed in Table I at 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 any temperature compensated materials listed in Table I, 3662 m/sec.

Other Temperature Compensated Materials

The sulfoalts are a class of materials of the form Tl$_3$B$_4$, 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$^{5,14}$. One particular cut of Tl$_4$V$_5$, for example, has four times the piezoelectric coupling of berlinite$^{13}$. 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$_3$TaSe$_4$, having zero electromechanical power flow angles, have also been found$^{15}$. 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 these sulfoalts 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 compensated$^{16}$. 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 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 $d_{13}$ 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 values$^{7}$. 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.

B-Eucryptite has also been shown to be temperature compensated. This lends further credence to the phenomenological model$^{8}$ which helps predict which materials may be temperature compensated. The piezoelectric coupling of B-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 B-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.

References


**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.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>ORIENTATION</th>
<th>EULER ANGLES $\lambda$, $\mu$, $\phi$</th>
<th>POWER FLOW ANGLE # (DEG)</th>
<th>SLOPE OF POWER FLOW ANGLE (dV/dt)</th>
<th>$\Delta V/V_0$ (X 10^-2)</th>
<th>SAW VELOCITY (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QUARTZ (SiO2)</td>
<td>ST CUT</td>
<td>0 132.75 0</td>
<td>0.0</td>
<td>0.378</td>
<td>0.058</td>
<td>3158</td>
</tr>
<tr>
<td>BERLINITE (AlPO4)</td>
<td>X AXIS BOULE 80.4°</td>
<td>0 80.4 0</td>
<td>0.0</td>
<td>0.901</td>
<td>0.245</td>
<td>2751</td>
</tr>
<tr>
<td></td>
<td>DOUBLY ROTATED, A</td>
<td>76.8 90 11.5</td>
<td>0.0</td>
<td>0.372</td>
<td>0.250</td>
<td>2756</td>
</tr>
<tr>
<td></td>
<td>DOUBLY ROTATED, B</td>
<td>79.7 90 15.5</td>
<td>0.0</td>
<td>0.221</td>
<td>0.247</td>
<td>2758</td>
</tr>
<tr>
<td>B-EUCRYPTITE (B-LiAlSiO4)</td>
<td>X CUT 69°</td>
<td>90 90 69</td>
<td>18</td>
<td>--</td>
<td>0.108</td>
<td>3662</td>
</tr>
<tr>
<td></td>
<td>DOUBLY ROTATED</td>
<td>0 57 62</td>
<td>0.0</td>
<td>0.32</td>
<td>0.035</td>
<td>3258</td>
</tr>
<tr>
<td>Tl3VS4</td>
<td>(110) CUT 70°</td>
<td>-45 90 70</td>
<td>-17</td>
<td>--</td>
<td>1.0</td>
<td>900</td>
</tr>
<tr>
<td></td>
<td>(110) CYLINDER 24°</td>
<td>45 24 90</td>
<td>0.0</td>
<td>--</td>
<td>0.617</td>
<td>1010</td>
</tr>
<tr>
<td>Tl3TaSe6</td>
<td>(110) CYLINDER 54°</td>
<td>45 54 90</td>
<td>0.0</td>
<td>--</td>
<td>0.508</td>
<td>879</td>
</tr>
<tr>
<td>SiO2/LiTaO3</td>
<td>Y CUT, Z PROP</td>
<td>0 90 90</td>
<td>0.0</td>
<td>--</td>
<td>0.7</td>
<td>3455</td>
</tr>
</tbody>
</table>

**Table 1.** Temperature Compensated cuts of various materials
Figure 2 - The variation of (a) SAW velocity, (b) electromechanical power flow angle, (c) piezoelectric coupling, and (d) temperature coefficient of time delay for X-cut $\beta$-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 $\beta$-eucryptite.

Figure 4 - Temperature coefficient of time delay versus piezoelectric coupling for various SAW materials.
TEMPERATURE COMPENSATED CUTS OF BERLINITÉ AND \(\beta\)-EUCRYPTITE FOR SAW DEVICES

Robert M. O’Connell
Paul H. Carr

SUMMARY

Calculations of the surface acoustic wave (SAW) properties of berlinité (\(\text{AlPO}_4\)) and \(\beta\)-eucryptite (\(\text{B}_2\text{LiAlSi}_2\text{O}_7\)) show that both materials are temperature compensated along both singly rotated and doubly rotated orientations. For berlinité, 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 \(\beta\)-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.

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KEYWORDS: Surface Acoustic Waves, Temperature Compensated Materials