Title: DEVELOPMENT OF IMPROVED LONG TIME APERTURE TE02A0 BRAGG CELLS FOR OPTICAL...

Administrative comments -
INITIATION. SUBCONTRACT SUPPORT FOR HARRY DIAMOND LABS (NO PRIME CONTRACT)
GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

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School/Lab EE

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Title Development of Improved Long Time Aperture TeO2 AO Bragg Cells for Optical Signal Processing Applications

Effective Completion Date 1/10/89 (Performance) 1/10/89 (Reports)

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- None
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- Government Property Inventory & Related Certificate
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- Research Security Services

- Reports Coordinator (OCA)
- GTRC
- Project File
- Contract Support Division (OCA)
- Other
DEFINITION OF SYMBOLS

\( \Theta \)  
Optical angular spectrum

\( \Theta_1 \)  
Incident optical beam in crystal with respect to \( Z' \) axis  
(see Figure 4)

\( \Theta_{10} \)  
Incident optical beam at tangential frequency

\( \phi \)  
Incident optical beam with respect to \( Z \) axis (see Figure 3)

\( \Theta_2 \)  
Diffracted optical beam

\( \Theta_a \)  
Acoustic beam direction

\( \Theta_a' \)  
Acoustic beam direction plus offset angle \( \Theta_{ao} \)

\( \Theta_{ao} \)  
Offset acoustic angle

\( \alpha \)  
Integration limit for \( \Theta_a \)

\( \alpha_i \)  
Incident optical angle with respect to acoustic wavefront  
(see Figure 4)

\( \delta_\Theta \)  
\( = \alpha_i - \Theta_1 \)  
Angular mismatch

\( \delta_d \)  
Diffracted optical angle with respect to acoustic wavefront  
(see Figure 4)

\( \delta \)  
Optical rotary power = \( 4.84 \times 10^{-5} \) at .8 micron wavelength

\( n_e \)  
Extraordinary index at .8 micron = 2.3725

\( n_o \)  
Ordinary index at .8 micron = 2.2262

\( n_i(\Theta_1, \phi) \)  
Incident extraordinary index

\( n_d(\Theta_2, \phi) \)  
Diffracted ordinary index

\( f_t \)  
Tangential frequency

\( A_o \)  
Optical wavelength

\( f \)  
Acoustic frequency

\( V_a \)  
Acoustic velocity

\( L \)  
Transducer length

\( H \)  
Transducer height

\( M_2 \)  
Acoustic figure of merit

\((v/2)\)  
Modulation index

\( P_{ac} \)  
Acoustic power

\( H_2(f) \)  
AO transfer function

\( k_{inc} \)  
Incident optical phase vector

\( k_d \)  
Diffracted optical phase vector

\( \Delta k \)  
Mismatch phase vector

\( M_{110} \)  
110 axis unit vector

\( M_z \)  
\( Z' \) axis unit vector

\( \nabla \)  
Velocity vector

\( H_3(f) \)  
AO transfer function with acoustic angular spectrum

\( Id \)  
Overall AO transfer function

\( X(f) \)  
Transducer and tuning network transfer function
ANALYSIS OF ROTATED Z AXIS ANISOTROPIC INTERACTION IN TeO2

I. Introduction

The purpose of this study is to improve the performance of TeO2 devices for signal processing, and a prerequisite is to understand the theory of anisotropic interactions in TeO2. This work was started prior to the award of this program and a paper (ref. 1) was published in SPIE. The Harry Diamond Lab broad agency program allows the extension of the earlier work in the following areas:

a) A generalized approach to calculate the momentum mismatch vector $\Delta k$ for isotropic and anisotropic interactions instead of Dixon's equation.

b) From this generalized approach, it is now possible to calculate efficiency and bandwidth simultaneously from one unified expression, previously not done for anisotropic AO interactions.

c) From the generalized approach, the effects of transducer diffraction and incident optical beam divergence are included to model practical situations more closely.

d) Improved software codes to calculate the anisotropic interactions.

All of these improvements will lead to results that show quantitatively the advantage of the rotated Z AO interaction.

II. Background on Anisotropic TeO2 Interaction

TeO2 interaction (ref. 2 & 3) is advantageous because:

a) The velocity of the material is slow resulting in a large time aperture Bragg Cell.

b) The acousto optic interaction is tangential and the phase mismatch is small for near tangential interaction situations, see Figure 1a, and as a result a large interaction length can be used.

However there are situations such that the operating frequency are higher than the tangential frequency, as shown in Figure 1b. In this case the phase mismatch becomes quite large as in isotropic interactions and a short interaction length must be used. The rotated Z anisotropic interaction improves this deficiency and is discussed in the next section.
III. Advantages of the Rotated Z Anisotropic Interaction in TeO2

TeO2 crystals are advantageous because of material availability and the long time aperture that can be achieved. One disadvantage of the normal anisotropic interaction is the tangential frequency is fixed for a given wavelength. Specifically, at the 830 nm wavelength, the tangential frequency is 25 MHz, and for most applications the center frequency should be at 50 or 70 MHz as illustrated in the momentum diagram in Figure 1. If the TeO2 device operates at 50 MHz and away from the tangential condition, then the AO interaction approaches that of the normal isotropic interaction with a large $\Delta k$ and loses the advantage of the tangential interaction in having a long interaction length. The interaction length advantage for tangential interaction over normal AO interaction is at least three times and will be discussed in detail in the examples in a later section of this report. The rotated Z allows changes of tangential frequency as a function of the rotation angle. Figure 2 illustrates the change of the extraordinary index surface as a result of rotation of the Z axis. The overall advantages of the rotated Z at 800 nanometers wavelength are as follows:

a) Choose center frequency to correspond with tangential interaction by the amount of rotation in the Z axis, e.g.

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Center Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 deg</td>
<td>25 MHz</td>
</tr>
<tr>
<td>3.7 deg</td>
<td>50 MHz</td>
</tr>
<tr>
<td>5.9 deg</td>
<td>70 MHz</td>
</tr>
</tbody>
</table>

b) As a result of tangential interaction the interaction length can be increased by 4.2 times resulting in lower input RF drive power.

c) Linear polarization is employed instead of circular polarization with improved light efficiency. See reference 4 for ellipticity of the polarization.

In an anisotropic interaction, it is also advantageous to set the incident beam $\theta_1 > \theta_{10}$, ref. 1, slightly away from the exact tangential condition at the center frequency with three improvements.

i) A center dip to balance transducer bandwidth to give a flatter overall bandwidth.

ii) $\Delta k$ is reduced by about a factor of 2 over the tangential matching resulting in optimum choice of the interaction length.

iii) We wish to point out that the effect of degeneracy is reduced at $f_0$ because the mismatch is maximum at $f_0$ and coupling into the second order will be further mismatched by $\Delta k$ maximum.
To illustrate the improvements, examine Figures 5 and 6. The tangential interaction for the incident beam set at $\Theta_{10}$ is shown in Figure 5. The match is at $f_0$ and the mismatch is at the upper and lower end of the frequency band. Notice in a finite acoustic lobe with a distribution of acoustic wave vector direction, only one half of the acoustic-wave vector direction is used. In this particular case, only wave directions to the left of the center acoustic-wave vector is used. The other half of the acoustic energy is thereby wasted. In Figure 6 we illustrate the case of the incident beam slightly larger than $\Theta_{10}$. In this case the maximum mismatch is at the center frequency and less at the upper and lower ends. If we connect a vector from the incident wave in the Ne surface to different points on the No surface as the acoustic frequency varies, we will notice that both directions of the acoustic-wave vector are used in the phase matching, thus this is a better approach.

IV. Rotated Z TeO2 Theory

The earlier work in ref. 1 covered the basic theories of the rotated Z TeO2 interaction. We will continue with the basic equations from this paper leading to the Dixon equations. The new work will be the derivation of the generalized $\Delta k$ equations and the efficiency analysis as well as optical beam divergence, acoustic wave divergence and misalignment.

a) Definition of angles. Refer to Figure 3 and 4. The following are defined:

$\phi$ is rotation of Z axis to Z' axis angle
$\Theta_1$ is incident angle in TeO2 with respect to Z' axis.
$\Theta_2$ is diffracted angle in TeO2 with respect to Z' axis.
$\Theta_a$ is acoustic wave wavefront angle.
$\Theta_i$ is incident laser angle with respect to $\Theta_a$.
$\Theta_d$ is diffracted laser angle with respect to $\Theta_a$.
$\delta$ is optical rotary power.

b) Write refractive index formulas $n$ (extraordinary):

$$n_i(\Theta_1, \phi) = \frac{n_{e_0}(1+\delta)}{\left\{n_0^2(1+\delta)^2 \sin^2\Theta_1 \cos^2\Theta_1 \sin^2\phi + n_e^2 \cos^2\Theta_1 \cos^2\phi\right\}^{\frac{1}{2}}}$$  

and $n_d$ (ordinary wave)

$$n_d(\Theta_2, \phi) = n(0, \phi) = \frac{n_0(1-\delta)}{\left\{\cos^2 \phi + (1-\delta)^2 \sin^2 \phi\right\}^{\frac{1}{2}}}$$
c) Tangential condition. From the tangential condition, we can obtain the center operating frequency $F_0$ and the angle $\theta_{10}$. These are obtained from the following equations:

$$F_0 = \frac{V_a}{\lambda_o} [n_i^2 - n_d^2]^{\frac{1}{2}}$$  \hspace{1cm} \text{--(4.3)}

$$\cos\theta_{10} = \frac{n_d}{n_i} \hspace{1cm} \text{(at tangential condition)} \hspace{1cm} \text{--(4.4)}$$

At tangential condition $n_i$ is simplified to:

$$n_i^2 = n_e^2 + \left[1 - \frac{n_e^2}{n_o^2(1+\delta)^2}\right] n_d^2 \cos^2 \theta$$  \hspace{1cm} \text{--(4.5)}

Refer to Figure 5 for the tangential angle.

d) We next find the angle $\theta_i$ from the Dixon's equation.

$$\sin \theta_i = \frac{\lambda_o}{2n_i V_a} \left\{ f + \frac{V_a^2}{\lambda_o f} (n_i^2 - n_d^2) \right\}$$  \hspace{1cm} \text{--(4.6)}

$$\sin \theta_d = \frac{\lambda_o}{2n_d V_a} \left\{ f - \frac{V_a^2}{\lambda_o f} (n_i^2 - n_d^2) \right\}$$  \hspace{1cm} \text{--(4.7)}

where $V_a = 616 \text{ m/sec}$

Once $\theta_i$ is solved then we can find the equation, calculate the equivalent acoustic wave deviation $\theta_a = \theta_i - \theta_1$ and make use of the transducer response to get the bandshape.

$$H_1(f) = \frac{\sin^2(\frac{\Pi L \theta_a f}{V})}{\left(\frac{\Pi L \theta_a f}{V_a}\right)^2}$$  \hspace{1cm} \text{--(4.8)}

Using the transducer response alone to calculate the frequency response may be not as accurate. So we will discuss a more generalized approach which is the work sponsored by this program.
e) Generalized Approach

In acousto optics a generalized expression for efficiency and bandwidth is (ref. 5):

\[
\left( \frac{E_d}{E_i} \right)^2 = H_2(f) = \left( \frac{v}{2} \right)^2 \sin^2 \left( \frac{(v/2)^2 + (\Delta kL)^2}{2} \right) \frac{1}{2} \left( \frac{R}{L} \right) \frac{H^2}{Pac} \frac{L}{\lambda_0} \left[ \frac{M_2}{H^2} \right]^{1/2} \text{ (Ref. 5)}
\]

where \( v = \frac{\lambda_0}{\lambda_0} \left[ \frac{\lambda_0}{H^2} \right]^{1/2}, \ M_2 \) is the figure of merit

\[ L = \text{Interaction length}, \ H = \text{Transducer Height}, \ Pac = \text{Acoustic Power} \]

\( \Delta k = \text{phase mismatch} \)

This expression allows the calculation of both bandwidth and efficiency. The key is to find the momentum phase mismatch vector which in some sense is more general than solving the Dixon equations.

Refer to Figure 7 for the various momentum vectors. The refractive index surfaces are suitably expressed in terms of \( \Theta I \) in equations 4.1 and 4.2.

The conservation of momentum vector is expressed as:

\[ \vec{k}_d + \Delta \vec{k} = \vec{k}_{inc} + \vec{k}_a \]  

\[ \text{when } k_{inc} = \frac{2\pi n_i}{\lambda_0}, \ k_d = \frac{2\pi n_d}{\lambda_0}, \ k_a = \frac{2\pi f}{v_a} \]  

and \( \Delta k \) is configured such that:

\[ \Delta \vec{k} = \Delta k \hat{z} \]  

Along the integration path, the vector notation is:

\[ \vec{v} = v_{xx} \hat{x} + v_{zz} \hat{z} \]  

where \( \hat{x} \) is the +110 axis  
\( \hat{z} \) is the rotated z axis
Along the \( x \) direction, the equation is:

\[
kd = kinc + Kax \tag{4.15}
\]

\[
kdsin\theta_2 = kincsin\theta_1 - Kacostheta'\]

Where \( \theta' = \theta_a + \theta_{ao} \). The acoustic wave vector has a mis-alignment angle \( \theta_{ao} \).

Along the \( z \) direction the equation is:

\[
kdz + \Delta kz = kinc + Kaz \tag{4.16}
\]

\[
\Delta kz = kinc + Kaz - kdz
\]

\[
= kinc cos\theta_1 + Kasin(\theta_a) - kd cos\theta_2
\]

By combining equations 4.16 and 4.15, we obtain:

\[
\Delta kz = kinc cos\theta_1 + Kasin\theta_a - K_a [1 - (\frac{K_a cos\theta_1 - kinc sin\theta_1}{kd})^2]^{\frac{1}{2}} \tag{4.17}
\]

For a collimated transducer and no acoustic wave misalignment, \( \theta_a = 0 \), then the \( \Delta kz \) is:

\[
kinc cos\theta_1 - kd [1 - (\frac{K_a kinc}{kd} kinc sin\theta_1)]^{\frac{1}{2}} \tag{4.18}
\]
Inclusion of transducer diffraction effects.

The generalized expression includes the angular spectrum of the acoustic wave $\Theta a$, and is as follows:

$$H_3(f) = c \int_{-\infty}^{\infty} \frac{(\frac{\nu}{2})^{2} + (\frac{\Delta k L}{2})^{2}}{(\frac{\nu}{2})^{2} + (\frac{k L}{2})^{2}} \frac{1}{x(f)} \sin^2 \left( \frac{\pi L f \Theta a}{v} \right) d\Theta a$$

Where: $\Theta a$ is a suitable limit such that the acoustic field intensity is small, $x(f)$ is the transducer transfer function.

(Note: The distinction in angular spectrum from acoustic diffraction. Acoustic diffraction will be treated in the second phase of the technical report.)

For angular spectrum of incident light beam:

$$Id = c' \int H_3(f) \cdot \exp(-s \Theta^2) d\Theta$$

$s$ is half divergence angle in radians.

We have derived the generalized expression for AO interaction in rotated Z TeO2. It is fairly straightforward to compare $A k$ with the results obtained from Dixon's equations. In the general case where the modulation index $\frac{\nu}{2}$ also contributes to the SINC function, then no comparison can be made because of the limitation of Dixon's equations. A later section will discuss results of the computer analysis derived from the above equations.
CONCLUSION OF ANALYSIS

We have derived a general expression for the analysis of anisotropic interaction in TeO2. The key results are as follows:

1) A generalized expression to calculate bandwidth and efficiency. The phase mismatch expression is identical to that derived from Dixon's equation.

2) Analyze the results in terms of acoustic and optical misalignment as well as the angular spectrum for the acoustic transducer and the optical beam. It is important to include the optical beam divergence effects for the laser diode wavelength.

The data presentation and analysis will highlight these conclusions.

REFERENCES


Figure 1a. Tangential Interaction

Figure 1b. Non-tangential Interaction

Figure 1. Anisotropic AO Interaction for Te02 at .8 Micron Wavelength
FIGURE 2
Tangential Frequency for Various Z Rotations

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Tang. Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 deg 25 MHz</td>
</tr>
<tr>
<td>B</td>
<td>3.7 deg 50 MHz</td>
</tr>
<tr>
<td>C</td>
<td>5.9 deg 70 MHz</td>
</tr>
</tbody>
</table>
FIGURE 3

ROTATED Z ANISOTROPHIC BRAGG INTERACTION K VECTOR DIAGRAM
ACOUSTIC WAVE PROPAGATION 110
\( \theta_1 = \theta_i + \theta_a \)

\( \theta_2 = \theta_d - \theta_a \)

FIGURE 4

Anisotropic Interaction Angular Relationship
FIGURE 5
ROTATED Z tangential anisotropic interaction. $\theta_1 = \theta_{10}$
Δk is maximum at \( f_0 \) and is less than Δk for the tangential interaction by about a factor of 2.

FIGURE 6

ROTATED Z slightly non-tangential anisotropic interaction. \( \theta_1 > \theta_{10} \)
FIGURE 7

Momentum Interaction Diagram

\[ \vec{k}_{inc} + \vec{K}_a - \vec{k}_d = \Delta \vec{k} \]
V. Data Analysis

a) $\Delta k$ Results:

The emphasis in this analysis is the phase mismatch factor $\Delta k$. The first computation is comparing Dixon's equation results with the direct calculation of $\Delta k$. We write $\Delta k$ (eq. 4.8) as:

$$\Delta k |_{\text{Dixon}} = 2\pi \frac{\theta_0 f}{V_a} \quad -(5.1)$$

Interestingly enough $\Delta k |_{\text{Dixon}}$ and $\Delta k |_{\text{generalized}}$ are identical as data presented in Figure 8.

The next plot is (Figure 9) $\Delta k$ (in m$^{-1}$ units) for 0 degree rotation and 3.7 degrees rotation with the incident angle at 1.6 degrees and the case at 1.67 degrees. For the 0 degree case it is seen that the rate of change in $\Delta k$ is minimal at 30 MHz and then becomes more rapid until there is a linear relation with frequency which is the same as the isotropic case. In the tangential case, ($\theta_1 = 1.6$ degrees) the variation is from 0 to -1000 (m$^{-1}$), and only acoustic angles in one direction is used (see Figure 5). In the optimum case, the incident angle is 1.67 degrees and $\Delta k <500$ m$^{-1}$. Compared with the non-rotated case, the $\Delta k$ is 4.2 times less, so for similar results, the interaction 4.2 times longer. The generalized equation allows the calculation of efficiency and bandwidth simultaneously.

b) Efficiency calculations using the generalized equation 4.19, the following cases are considered.

i) 0 degree rotation for 35 to 65 MHz with 1%, 2%, 10% and 25% efficiency, the curves are plotted with power levels shown in Figures 10 and 11.

ii) 3.7 degrees rotation for 35 to 65 MHz with 1%, 2%, 10% and 25% efficiency. The curves are plotted with power levels in Figures 12 and 13.

iii) 5.9 degrees rotation for 50 to 90 MHz with 10% and 25% efficiency. The curves are shown in Figure 14.

In all cases, the efficiency versus power is relatively linear from 35 to 65 MHz. Figure 15 is a summary of the results of Figure 10 - 14. The 3.7 degree device requires four times less drive power. When the bandwidth is increased to 40 MHz, the drive power also increases to 8.8 milliwatts versus 3.2 milliwatts.
<table>
<thead>
<tr>
<th>Frequency</th>
<th>$\Delta k_{\text{km}^{-1}}$ Dixon Eq.</th>
<th>$\Delta k_{\text{km}^{-1}}$ Generalized Eq.</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>-680.7799</td>
<td>-679.9326</td>
</tr>
<tr>
<td>35</td>
<td>-160.8581</td>
<td>-159.92</td>
</tr>
<tr>
<td>40</td>
<td>210.2713</td>
<td>211.071</td>
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<tr>
<td>45</td>
<td>432.6253</td>
<td>433.0403</td>
</tr>
<tr>
<td>50</td>
<td>560.21</td>
<td>507.0301</td>
</tr>
<tr>
<td>55</td>
<td>431.0279</td>
<td>431.9982</td>
</tr>
<tr>
<td>60</td>
<td>207.0753</td>
<td>207.9446</td>
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<tr>
<td>65</td>
<td>-165.653</td>
<td>-165.1305</td>
</tr>
<tr>
<td>70</td>
<td>-687.1608</td>
<td>-686.1852</td>
</tr>
</tbody>
</table>

Figure 8. Comparison of $\Delta k$ for rotated Z cut TeO2 at PHI = 3.7°, THI = 1.67°
Momentum Mismatch for Anisotropic Rotated Z cut TeO2

---

**FIGURE 9.**

- \( \phi \) \( \theta_1 \)
  - A 3.7 1.67
  - B 3.7 \( \theta_{10} = 1.6 \)
  - C 0 1.1

---

Graph showing phase mismatch vs. frequency (f MHz) with labeled curves for A, B, and C.
FIGURE 10.

L = 1.06 mm
30 MHz Bandwidth = 1.2 dB
L = 1.06 mm, PE = .013 at 1% efficiency
30 MHz Bandwidth = 1.2 dB

FIGURE 11.
**FIGURE 12.**

- **Frequency Response**: $\Phi_1 = 3.7$ and $\theta_1 = 1.67$
- **Frequency Range**: 30 MHz
- **Bandwidth**: 30 MHz, 1.59 dB
- **Length**: $L = 4.27\,\text{mm}$
FIGURE 13.

FREQ RESPONSE PHI = 3.7 TH1 = 1.67

L = 4.27mm
30 MHz Bandwidth = 1.59 dB
\[ L = 1.64 \text{ mm} \]
\[ 40 \text{ MHz Bandwidth} = 1.58 \text{ dB} \]

**FIGURE 14.**
<table>
<thead>
<tr>
<th>PHI</th>
<th>L(mm)</th>
<th>30 MHz Bandwidth (dB)</th>
<th>Drive Power for 1% Efficiency (milliwatt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.06</td>
<td>1.2</td>
<td>12.8</td>
</tr>
<tr>
<td>3</td>
<td>4.27</td>
<td>1.6</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40 MHz</td>
<td></td>
</tr>
<tr>
<td>5.9</td>
<td>1.64</td>
<td>1.6</td>
<td>8.8</td>
</tr>
</tbody>
</table>

Figure 15. Comparision of Results
c) By including the transducer angular spectrum, which better matches the AO interaction, the bandwidth improvement is from 1.2 to .7 dB for PHI = 0, and from 1.6 to .9 dB for PHI = 3.7 degrees. The peak efficiency does not change. Figures 16 and 17 illustrate the cases including transducer angular spectrum.

d) Optical angular spectrum is also considered in the analysis and may be important for ILD laser wavelength. This effect degrades the high frequency performance as shown in Figures 18 and 19.

These graphs demonstrate how the key parameters variation affect the AO interaction bandwidth. And they must all be considered for an optimum design.
COMPARISON WITH XDR DIFFRACTION

L = 1.6mm, Q = 15.77
30 MHz Bandwidth = .7dB

FIGURE 16.
Comparison with XDR Diffraction

\[ L = 4.28 \text{ mm}, \quad \text{PHI} = 3.7 \text{ degrees}, \quad \theta_1 = 1.67 \text{ degrees} \]

30 MHz Bandwidth

FIGURE 17.
\( \phi = 3.7 \) degrees,  \( L = 4.28 \) mm
\( H = 3.0 \) mm,  \( PE = 34 \) mwatts

FIGURE 18.
\[ \lambda = 3.7 \text{ degrees}, \quad L = 4.28 \text{ mm} \]
\[ H = 3 \text{ mm}, \quad PE = 34 \text{ mwatt} \]

**FIGURE 19.**
e) Optical and Acoustic Beam Misalignment. Both optical and beam misalignment can be used to adjust the overall bandshape. These curves are shown in Figure 20 through Figure 22.
Changing Incident Optical Angle
A $\theta_1 = 1.67$ degrees
B $\theta_1 = 1.62$ degrees
$L = 4.28$ mm, $\phi = 3.7$ degrees

FIGURE 20.
Changing Incident Optical Beam

A \( \theta_1 = 1.67 \) Degrees
B \( \theta_1 = 1.69 \) Degrees
L = 4.2 mm

FIGURE 21.
FIGURE 22.

ACOUSTIC ANGLE MISALIGNMENT = .05 DEGREE

FREQUENCY
APPENDIX A

The computer programing flow chart for the anisotropic equation frequency response using both Dixon's equations and the generalized approach in \( \Delta k \) is attached. The program is in an executable file, HDL.BAT.
FLOW CHART FOR COMPUTER PROGRAMMING

START

Input R, VA
PHI = (\phi), Mode Index
LAM = (\lambda)
no = 2.2862
ne = 2.3725
DEL = (\Delta) = 4.84 \times 10^{-5}

Find parameters at tangential frequency:
* Tangential Frequency
* Angles at Tangential Freq

Input \Omega > \Omega 0
Find parameters at operating frequency:
* L0
* L
* \delta
* Mismatch Angle \delta

Frequency Response
Solve Dixon's equation
Solve generalized \Delta k

Increment Frequency

Screen Display

Print Option

Plot Option

END