On the efficiency of backward collinear acousto-optic interaction between terahertz radiation and acoustic beam in hexane

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Synchrotron and Free electron laser Radiation: generation and application (SFR-2020)
Acousto-optic interaction

Basic principals

\[ \frac{l_1}{l_0} \propto \frac{1}{\lambda^2} \cdot \exp(-\alpha L) \cdot M_2 \cdot P_a \]
Under theses regime, the highest spectral resolution can be achieved. Sound with ultrahigh frequencies should be used: 

\[ F \approx 1 \text{ GHz at } \lambda \approx 1 \mu \text{m and } F \approx 10 \text{ MHz at } \lambda \approx 100 \mu \text{m} \]

\[ F = 2 \cdot n \cdot V / \lambda \]

The distance \( z_0 \) from sound transducer to input optical window is about several centimeters.
Backward collinear AO interaction

Hexane as the best medium of AO interaction

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A review of non-polar liquids as materials for bulk acousto-optic devices operating with terahertz radiation

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Table 1. Acoustical, optical and acousto-optical properties of selected liquids.

<table>
<thead>
<tr>
<th>liquid</th>
<th>$\rho$ (g/cm³)</th>
<th>$V$ (km/s)</th>
<th>$\alpha_s / (2F^2)$ ($10^{-17}$ s²/cm)</th>
<th>$n$</th>
<th>$\alpha$ (cm⁻¹)</th>
<th>$M_2$ ($10^{-15}$ s³/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₆H₁₄</td>
<td>0.655</td>
<td>1.077</td>
<td>60</td>
<td>1.372</td>
<td>0.69</td>
<td>847</td>
</tr>
</tbody>
</table>

Table 3. Properties of acousto-optic filters based on liquids.

<table>
<thead>
<tr>
<th>liquid</th>
<th>$F$ (MHz)</th>
<th>$\alpha_s$ (cm⁻¹)</th>
<th>$I_{-1} / I_0$, ($10^{-4}$)</th>
<th>$R$ ($10^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₆H₁₄</td>
<td>21.1</td>
<td>0.5</td>
<td>9.3</td>
<td>0.6</td>
</tr>
</tbody>
</table>

\[
\frac{I_{-1}(0)}{I_0(0)} = \frac{\pi^2 M_2 P_a}{2 \lambda^2 S} \left( \frac{\alpha + \alpha_s}{2} \right)^{-2}
\]

\[
R = \frac{k}{\Delta k} = \frac{2 \pi n}{\lambda} \frac{1}{\alpha + \alpha_s / 2}
\]
Sound beam modelling

Method - Fourier transform (PZT - 5x5 mm)
Sound beam modelling

AO coupling coefficient

\[ |q(x,z)| \]

\[ \text{phase of } q(x,y) \]

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AO diffraction

Infinite light beam ($\lambda = 130 \, \mu m$, $z_0 = 0 \, cm$)
AO diffraction

Gaussian light beam ($\lambda = 130 \, \mu m$, $z_0 = 0 \, cm$)

\[
I_0(x) = \sigma \sqrt{2\pi} e^{-\frac{x^2}{2\sigma^2}}
\]

\[
I_1 = 10 \times 10^{-4}
\]

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AO diffraction

Gaussian light beam ($\lambda = 130 \, \mu m$, $\sigma = 2.5 \, cm$)
Conclusion

- Theory of 2D acousto-optic interaction was applied to the regime of backward collinear diffraction.
- The acoustic field in liquid was modelled by Fourier transform method.
- It was established that diffraction efficiency is the highest for narrow THz light beam ($\sigma < 1$ mm) (half THz beam diameter) and decreases as $1/\sigma$ at $\sigma > 1$ mm, as the light beam becomes wider than the sound beam.
- It was shown diffraction efficiency decreases with distance $z_0$ from piezo-electric transducer (PZT) to input optical window due to sound attenuation.

Acknowledgments

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Any questions