Acousto-Optics

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The aim was to better understand acousto-optic devices through studying the operation of an acousto-optics deflector and a modulator and differentiating between Bragg and Raman-Nath diffraction. It was concluded that Bragg diffraction is characterized by the production of a single diffracted beam; whereas, Raman-Nath diffraction is characterized by the production of multiple diffracted beams.

INTRODUCTION

In 1922, the interaction between light and acoustic sound waves in a transparent medium was theorised by Brillouin. He found that light would scatter from thermally excited elastic waves in a crystal which would be diffracted in both solids and liquids. He predicted that an interference pattern with its maximum peak intensities at specific angles known as Bragg Angles, similar to Bragg's Law and Bragg Diffraction with X-rays in crystals.

This phenomenon was successfully demonstrated by Debye and Sears' experiment in 1932 using artificially generated elastic waves. This allowed them to precisely control the acoustic waves, which in turn allowed them to control and modulate the transmitted light at specific frequencies, amplitude and the direction.

However, when varying the parameters, higher order diffractions appeared with different intensities which could not be explained by Brillouin's theory. It wasn't until 1937 that Raman and Nath produced their theory explaining the intensities distribution in higher order diffractions - now known as Raman-Nath Diffraction.

With the advancement of lasers, crystal growing techniques and high frequency piezoelectric transducers, modern acousto-optic devices allow precise control of optical deflection, modulation, frequency shifting and much more. Hence, they are commonly used in applications such as civil and biomedicine for structural monitoring, Q-switching in pulsed operating lasers and signal processing in optical fibres.

METHOD

See UNSW PHYS3112 Acousto-Optics Student Notes pdf

AIM

To study the operation of an acousto-optic deflector and of a modulator and hence to gain an understanding of acousto-optic devices and the differences between Bragg and Raman-Nath diffraction.

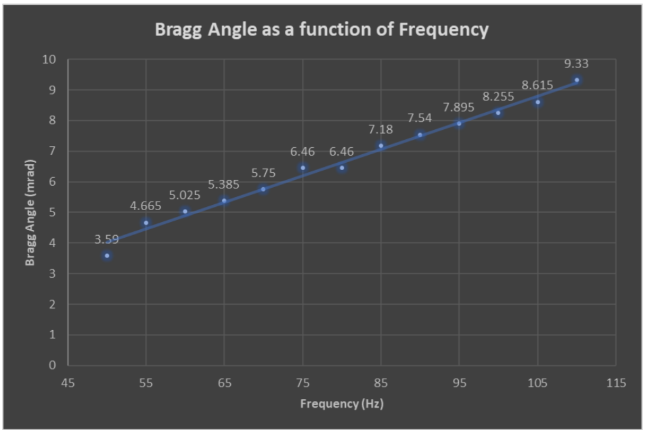

FIG. 1. Regression Fit: 0.0867x - 0.3129. All quoted Bragg angles have an error of ± 0.36 mrad

RESULTS & ANALYSIS

Bragg Diffraction

- RF Power Amplifier Gain Calculation

$$\text{Gain}=\frac{V_{out}}{V_{in}} \tag{1}$$

V_{out} =Amplified Signal V_{pk-pk}=10.800V ±0.001V
V_{in} =Signal Generator V_{pk-pk}=0.239V±0.001V

$$\text{Gain} = \frac{10.8}{0.239} \approx 45.19$$

- Velocity of Ultrasound

$$\text{velocity of ultrasound} = \nu = f_{RF}\Lambda = f_{RF}\frac{\lambda}{2\sin(\theta_B)} \tag{2}$$

f_{RF}=Generator frequency (Hz)
Λ=Acoustic wavelength (m)
λ=Laser wavelength (m)
θ_B=Bragg angle (rad)
The calculation of the Bragg angle was performed three times with the frequency generator set to 70 Hz and then the average Bragg angle was used to find the acoustic wavelength. The Helium-Neon Laser had a wavelength of 633 nm. To find the Bragg angle, the distance from the laser source to the screen was measured

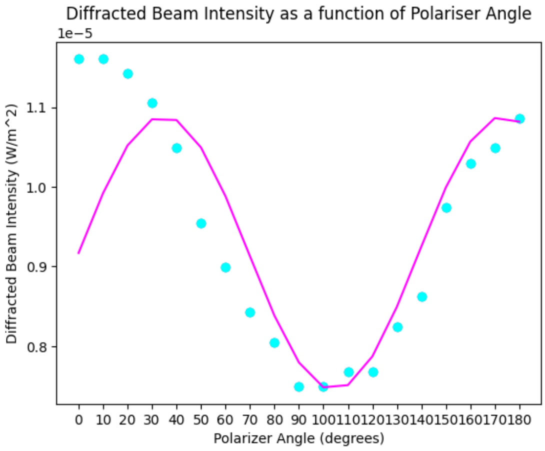

FIG. 2.

to be 1393mm. The distances between the first order beams on either side of the zeroeth order beam were measured on the screen to be 1.7cm, 1.6cm, and 1.6cm all ± 0.5mm. Using basic trigonometry, the deflection angles were found to be 12.2mrad ± 0.36mrad, 11.5 mrad ± 0.36mrad, and 11.5 mrad ± 0.36mrad with an average of 11.85mrad±0.36mrad. Dividing by 2, the average Bragg angle was 5.75mrad±0.18mrad

$$\nu = 70(10^6)Hz\frac{633(10^{-9})m}{2\sin(5.75(10^{-3})rad)}$$

$$= 3853.06m/sec \pm 189.54m/sec$$

- Impact of High RF Frequencies
  High RF frequencies cancel out the Bragg diffraction with the intensity of the first order deflected beam decreasing to zero volts at an RF frequency of 110Mhz from an intensity of 2 volts at 70MHz. Interestingly, the deflected beam increases in separation distance from the zeroeth order beam until it reaches peak intensity at 70Mhz. Then, it jumps a few mm further past the distance it was from the zeroeth order beam at 70MHz and immediately darts back upon the transition to 80 Mhz then decreases in intensity as separation distance increases until the first order beam is no longer distinguishable.

- Diffracted Beam Intensity as a Function of Polarizer Angle (See FIG. 2. and FIG. 3.)
  The results depicted by the plot of FIGs 2. and 3. were expected because the laser is polarized in a single plane so when the polarizer is rotated it picks out a component of the the beam so that the power transmitted by the beam is a sine wave, with intensity being proportional to power.

	Polarizer Angle (degrees)	Diffracted Beam Intensity (W/m^2)
0	0.0	0.000012
1	10.0	0.000012
2	20.0	0.000011
3	30.0	0.000011
4	40.0	0.000010
5	50.0	0.000010
6	60.0	0.000009
7	70.0	0.000008
8	80.0	0.000008
9	90.0	0.000007
10	100.0	0.000007
11	110.0	0.000008
12	120.0	0.000008
13	130.0	0.000008
14	140.0	0.000009
15	150.0	0.000010
16	160.0	0.000010
17	170.0	0.000010
18	180.0	0.000011

FIG. 3. Fitted Sine Function: $1.718^{-6}\sin(0.0452x)+ 9.167^{-6}$. The degree measurements have errors of ±0.5 degrees and the intensitites have errors of ±0.0067 W/m^2

Raman-Nath Diffraction

- Sound Recording
  The following link is to a video of *Sympathy for the Devil* by the Rolling Stones being played on a speaker by modulating a laser.

  https://drive.google.com/file/d/16xYfKAt$_2S5Hgw7qkLRy - TDFXqHduf5K/view?usp = sharing$

- Signal Modulation (See FIG. 4. and FIG. 5.)

  Over-modulation causes distortion of the output signal and occurs when the frequency of the modulating wave exceeds the maximum frequency of the carrier wave.

  Under-modulation also causes distortion of the output signal and occurs when the frequency of the modulating wave is much less than the maximum frequency of the carrier wave.

- Remaining Measurements (See FIG. 6.)
  The zeroeth order beam had a large DC voltage measurement but low AC voltage measurement because it was unmodulated. In contrast, the first order beams on either side had greater AC voltage measurements because they were modulated.

Modulator vs. Deflector

- Fundamental Difference between Modulator and Deflector

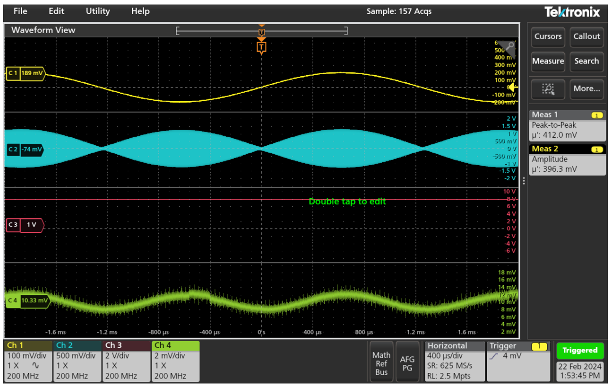

FIG. 4. 100% Modulation. Channel 1: Function Generator, Channel 2: Acousto-Optic Modulation, Channel 3: Photodiode 1 (zeroeth order), Channel 4: Photodiode 2 (first order)

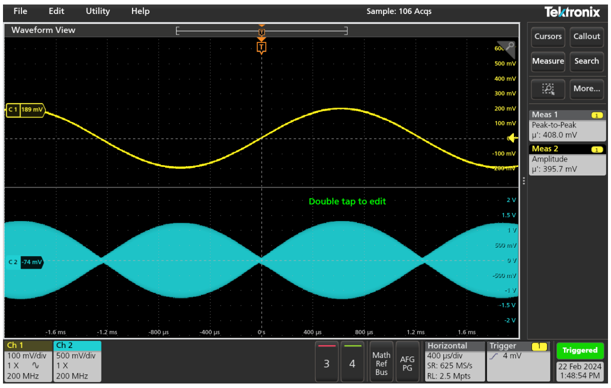

FIG. 5. The previous figure zoomed in on channels 1 and 2.

A modulator provides amplitude variations on a constant acoustic frequency while a deflector provides a constant amplitude but varying acoustic frequency.

CONCLUSIONS

The acousto-optic effect allows for the creation of acousto-optic modulators and deflectors because the refractive index of materials changes with the presence of sound waves in that material. For the Bragg regime, there is essentially a single diffracted wave produced since the others are annihilated by destructive interference; whereas, the Raman-Nath regime is characterized by multiple diffracted beams with intensities given by Bessel functions.

	Background (V)	Full Modulation (V)	No Modulation (V)
0th order	-0.003550	7.88200	7.8730
1st order left	-0.004393	0.07486	0.3712
1st order right	0.007838	0.03545	0.1769

	V peak-to-peak (AC) (V)	V mean (DC) (V)	Signal to Mean Value Ratio
0th order	0.0040	7.89800	0.000506
1st order left	0.1818	0.04797	3.789869
1st order right	0.1809	0.03047	5.936987

FIG. 6. All volt measurements in the above tables have errors of 0.05mV

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