Effect of Square Shaped Acousto–Optic Modulators on the Bragg Diffraction

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Abstract. The COMOSOL multiphysics is used to design various optical systems, including the design of the acousto-optic modulator system. Its work depends on the special inputs of the program, such as the characteristics of the laser used and the frequencies of the sound waves. A square modulator was designed with dimensions 3x3 mm, and a quartz crystal was used, in which the interaction of light and sound occurs. Different number of orders diffraction are generated called the Bragg angle, and their number varies with different inputs. The modulator is created by entering the value of the radio frequency up to 100 volts. Through our results, the efficiency increases at the frequency of 400 kHz after changing the frequencies of 200, 300 and 400 kHz. The values of the stress are: 1.24 x 10^6 Pa, 1 x 10^6 Pa, 3.8 x 10^6 Pa, and the estimated shift is about 0.7, 0.4 and 0.9 nm, there were three frequency values considered: 200, 300, and 400 kHz, respectively. The far field shape show two orders are appeared at 200 kHz and 300 kHz frequencies they are: zero order and first order but they are different in the value of Bragg angles but in 400 kHz shown approximate three orders, they are: zero, first, and new generation of second order with the different in the value of Bragg angles.

Keywords: Acousto-optics modulators, AO modulator transmission, AOM of high frequency, AOM of nonlinear crystal material, AOM diffraction efficiency.

1. Introduction

Modulators of acousto-optic are commonly used to accurately monitor intensities and frequencies of light at which the moving acoustic wave produced by the piezoelectric transducer produces a modulated index of refraction and causes Bragg diffraction in the incident light. [1]. The effect of electro-optic enables powerful and lightweight modulators and allows modulation of high frequency, it is an alternative approach for index modulation. Lithium niobate, for example, possess good electro-optic, piezoelectrical and nonlinear optical properties, it is a popular source for the construction of wavelength converters and discrete modulators that work in the spectrum region of infrared-visible [2]. Acousto-optic modulator (AOM) is a device allows to change the laser beam direction, strength, and frequency. Inside such instrument, a light from Bragg’s production offers two acoustic wavefronts that transmit inside the crystal. The modulation is carried out by varying the frequency or the amplitude of the wave that pass cross the crystal. The crest of maximum refractive index alternates with low refractive index troughs in the sound wave that pass through the crystal. The light that falls on the refractive index gradients is dispersed, the dispersion impact the acoustic wave fronts as figure 1 shows[3]. Acousto-optic systems are based on a photo-elastic or elasto-optic effect that creates a tension that affects the optical properties of the crystal as a result of an acoustic signal applied to an AO crystal. The acoustic signal is inserted into the crystal using apiezolectric transducer and creates compression and refraction regions as it propagates. It may be deflected or modulated as an optical beam travels through the crystal, which is changed in frequency. Changes in the crystal refraction index caused by the strain cause changes in the optical properties of the crystal. The full mathematical explanation of the photo-
elastic effect relies on the directional properties of the AO material and involves a tensor relationship between the elastic strain and the coefficients, several materials, such as Quartz crystal, are used from the visible to near infrared regions [4]. Simulation of the propagation properties of the various rectangular AOM materials: lithium niobate (LiNbO3, fused silica (SiO3), germanium (Ge), and tellurium dioxide (TeO2). This model uses a single crystal plate, in which the rotational symmetry of the element is kept [5].

Many literary works are written in the area of simulation and architecture of AO modulators. The distinctions between them apply to factors likes: modulator shape, material, input power, wavelength, and operating limits. The two-dimensional theoretical model of the strong interaction of acousto-optic uses a finite size beam with arbitrary profiles of curved front wave in the acoustic region is suggested in [6]. The corresponding computational analysis of diffraction characteristics shows that the diffraction efficiency and bandwidth in the acoustic area of the curved wave front is during acousto-optic interaction, the increase is at least 1.5 times at weak interaction and it is more than 5 times at strong interaction. [7]. The Mat lab program applies the acousto-optic contact simulation and correlates it with product of the experiment. It was also extensively noticed that simulation accuracy was used in a feedback circuit. The hybrid optical system was generated to achieve 1st and 2nd order feedbacks as well as physical visions into simulation's operations, while the coupling equations describing ultra-short optical pulse diffraction were extracted and modified. In the crystal between Eigen waves and anisotropic Bragg diffraction, there was a single hypothesis considering partial latency. The simulation's numerical results revealed a significant difference between standard theory and modified theory. It demonstrates that it is important to correctly describe the diffraction of acoustic-optic in femto-second pulses to solve the Bragg coupling problem in bi-refringent wave packet media [8].

2. Contribution
This research dealt with the determination of the parameters through which an acousto-optic modulator can be constructed. This causes the transmitting features of the engineered modulator to be measured to simulate its efficiency and increase the performance reliability. In addition, the simulation allows the built AO to operate with certain determined parameters in various circumstances with these variations. The square shape of the modulators can be used to quantify the properties of acousto-optic that can influence the performance of the suggested AO system output

3. Proposed Design of AOM
The proposed model of AOM is designed in square form by using Comsol multiphysics. This software provides many pre-built tools are used to design the acousto-optic modulators and simulate its performance, including the ability to set boundary conditions that necessary for the modeled AOM.
operating situation to be more realistic. Figure 2 shows the proposed square form of the AOM design, in which the dimensions of the acousto-optic medium are 3-3 cm, while the dimension of the piezoelectric transducer is 2-0.5 cm, which is selected from the material PZT-5H (Lead Zirconate Titanate) that widely employed in piezoelectric transducers. In this case, the crystal domain optical material is considered based on the square design of modulators is quartz crystal content used. At the building point, the used parameters are applied to Comsol, the trial and error showed that these parameters can be optimized to obtain optimal values for each parameter as present in table 1.

![Figure 2. Proposed design of square shape of the AOM by COMOSL.](image)

### Table 1. Optimal values of proposed AOM operating parameters.

| Operating parameter            | Value and unit |
|--------------------------------|----------------|
| Interaction length (L)         | L = 3 cm       |
| Modulator height (H)           | H = 3 cm       |
| Laser beam diameter (D)        | D = 3 mm       |
| Acoustic power (Pₐ)            | 0.5 watt ≤ Pₐ ≤ 2.5 watt |
| Focal length (F)               | F = 3 mm       |
| Operating signal laser wave length (λ) | λ = 1.6 μm   |
| Room temperature (T₀)          | T₀ = 300 K     |
| Ambient temperature (T)        | 300 K ≤ T ≤ 340 K |
| Quartz Based AOM device        |                |
| Material density               | ρ = 2.6 g/m³    |
| Refractive index               | n = 1.527      |
| Acoustic velocity              | vₐ = 5.75 (km/sec) |
| Figure of merit                | a. (10⁻¹⁸ s³/g) |

### 4. Results and Discussion

The acoustic pressure distribution quartz material domain using 400 kHz is shown in figure 3, in which Lead Zirconate Titanate (PZT-5H) is the piezoelectric transducer form. The values of the acoustic pressure are measured in Pascal (Pa) that plotted by colored scale on the side of each distribution along z-axis, whereas the modulator proportions are shown in the horizontal plane. The acoustic pressure is
shown to differ with frequency variation, with the maximum acoustic pressure values being $7.81 \times 10^5 \text{Pa}$.

![Figure 3. Total acoustic pressure field at 400kHz.](image)

Figure 4 represents sound pressure distribution in the domain of acoustic crystal in the frequency (400) kHz. The color scale shows the range of sound pressure that distributed along the side dimension of the modulator diagram.

![Figure 4. Distribution of sound pressure through domain of acoustic crystal in the value of frequency (400) kHz.](image)
Figure 6 shows the resulted far-field analysis that refers to the far field limits that drawn with 360° rotation angle. Such plane behavior indicates the number of diffraction orders aid to Bragg angle adjustment. It is seen that two orders exist at 200 kHz and 300 kHz frequencies they are: zero order and first order yet vary in the value of Bragg angles but in 400 kHz roughly three orders seen, they are: zero, first and latest second order generation with the difference in the value of Bragg angles.

Figure 5. Distribution of stress inside the piezoelectric domain for different values of frequencies 200, 300, 400 kHz
The two pointed locations shown in figures 7 refer to the horizontal change that showing the gap between the two diffractions of zero and first order, these points can only be seen in the operating RF level. The measured change at frequencies 200, 300, and 400 kHz is around 0.7, 0.4 and 0.9 mm respectively. With the shift in frequency, quite few changes can occur. If the number of orders increases, the modulator output may become more efficient. The angles between the moved light beams are comparatively small because of the proliferation of diffracted beams.

Figure 6. Levels of far field sound pressure in different values of frequencies 200, 300, 400 kHz.
5. Conclusion

Via the research above, we demonstrate that the square quartz modulator form has provided the best results in terms of efficiency in comparison with rectangular shape with various other materials[8]. As we remember, as the efficiency increases with the increase in the amount of order diffraction and also with the increasing of the Bragg angle, the efficiency at the frequency 400 kHz is the best possible of the other frequencies. Furthermore, by studying the form of the distance field at various frequencies, in particular at the 400 kHz frequency, the meaning of the change between the two points of shifting increases at the same frequency. At frequency 400 kHz the tension is optimum at the frequency at which the performance is the greatest.
6. References

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