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Characterization and optimization of the laser diffracted by an acoustic-optical modulator in the infrared region

J Barrios[1], J Álvarez[1], and F J Racedo[1]

[1] Grupo de Espectroscopia Óptica y Emisión Láser, Universidad del Atlántico, Puerto Colombia, Colombia

E-mail: franciscoracedo@mail.uniatlantico.edu.co

Abstract. The acousto-optic modulator is a popular tool in photonic laboratories for amplitude modulation or frequency tuning. Due to the unique feature of the modified frequency diffraction, the acousto-optic modulator can also serve as a key element in laser spectroscopy. In this work, the characterization of an acousto-optic system is presented. For the characterization of the beam, diffracted by this system, the modulators efficiency was optimized based on its vertical positioning, and also the beams angle and position. The profiles of the diffracted beams under the frequency modulation are shown up, down, and near of the modulation's central frequencyIn an AOM, the light is scattered from successive wavefronts that interoperate constructively. The condition for the constructive interference of scattered light is given by the Equation (1), in which the favoring of the orders diffracted by the modulator can be seen as predicted by the acousto-optic principle.

1. Introduction

The diffraction of light by an acoustic wave propagating in a medium of interaction was predicted by Brillouin in 1922 [1]. With this the physicists Debye and Sears [2], and with them Lucas and Biquard carried out their first experiments [3]. In that time the work on this phenomenon in the laboratory was not more than a pleasant experiment, where the only use was for the measurement of acoustic constants and their applications for the modulation and signal processing. It was not until technology allowed to advance in the development of crystal growth that the production of piezoelectric transducers was achieved, which nowadays bring great benefits in acousto-optic components [4]. Since then, the modulation of a laser beam plays an important role in the applications of atomic physics and spectroscopy. This can be seen in atom coding experiments, where the frequency of the laser must be stabilized at the atomic or molecular transition [5].

The modulation techniques of a laser beam can be classified into: direct modulation or indirect modulation. A variation of an active refractive index, current or in a length cavity produces a direct modulation. On the other hand, indirect modulation only occurs once the beam has left the cavity, in these cases acousto-optic modulators (AOM), electro-optical modulators (EOM) and mechanical cutters are used, the latter has physical limitations due to a frequency response, stability between each pulse, among other limitations. Accordingly, it is necessary to replace the circuit breakers with blocked modulators for frequency control, power control and beam deflection [4].

In this work, the characterization and optimization of the beam diffracted by an acousto-optic modulator was carried out. For the characterization of the system the performance of the AOM was optimized taking into account the angle and position of the beam entry, vertical positioning of the AOM and polarization of the laser beam. When obtaining the optimization of the system, the beam is observed using a CCD varying the frequency and amplitude of frequency radio modulation [6–8].

2. Acousto-optic principle

Acousto-optic modulators (AOM) are useful devices that allow to modulate the frequency, intensity and direction of a laser beam. Within these devices, the incoming Bragg's light gives two fronts of acoustic waves that propagate through a crystal. The modulation of this light can be achieved by varying the amplitude and the frequency of the waves traveling through the crystal [9].

Sound waves traveling through the crystal can be modeled as crests of higher refractive index that alternaternate with troughs of decreased refractive index. The light that falls on the gradients in the refractive index is scattered, therefore, the light is scattered from the acoustic wave fronts as shown in Figure 1 [10].

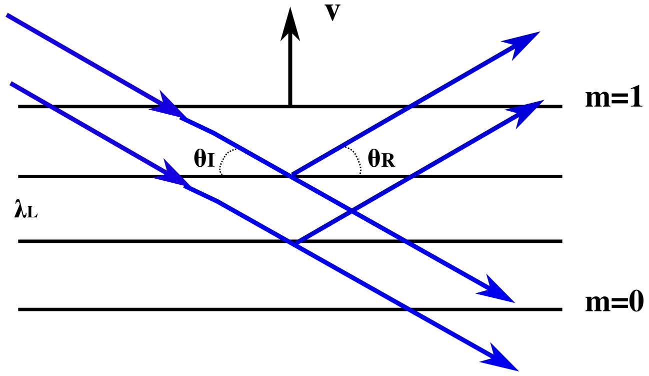

Figure 1. Acoustic wavefront.

In an AOM, the light is scattered from successive wavefronts that interoperate constructively. The condition for the constructive interference of scattered light is given by the Equation (1):

$$n\lambda_L = \lambda_{AC}\left(sin(\theta_i) + sin(\theta_d)\right). \quad (1)$$

For a dispersion of the optical wave of the sound with an order frequency of $10^8 Hz$, it is required for a conservation of energy and momentum that without $sin(\theta_i) = sin(\theta_d)$ in this way is given Equation (2):

$$n\lambda_L = 2\lambda_{AC} sin(\theta_d), \quad (2)$$

where λ_{AC} and to $m = 1$ we have to Equation (2) and give the Equation (3),

$$sin(\theta) = \frac{\lambda f_{AC}}{2v_{AC}}. \quad (3)$$

It can be noted that at a fixed acoustic velocity the Bragg angle depends only on the control of the acoustic frequency and the optical wavelength [10].

Taking into account the direction of incidence of the beam, the frequency of the deflected beam (f_{out}) could be greater or less than the frequency of the incident beam (f_{in}), below. In

Figure 2 and Figure 3, you can observe the dependence of the direction of incidence and modeled by Equation (4),

$$f_{OUT} = f_{IN} \pm f_{AC} \tag{4}$$

If the beam is directed against the direction of acoustic propagation, then the output frequency is higher than the input frequency and in the opposite direction.

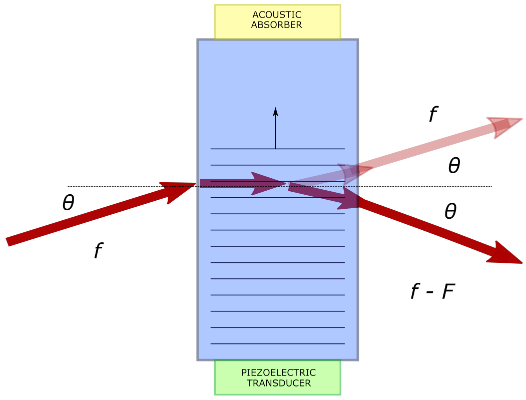

Figure 2. AOM on configuration.

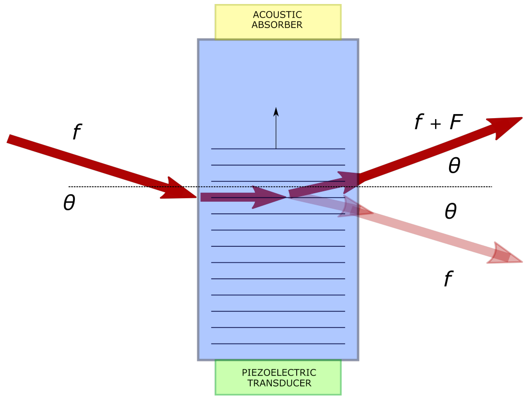

Figure 3. AOM off configuration.

The deviated beam power that depends on the power of the electric impulse can be calculated from the deflection efficiency using the Equation (5),

$$\eta = \frac{P_1}{P_0} = sin^2\left(\frac{k}{\lambda}\right) P_{RF,} \tag{5}$$

where P_1 and P_0 are the optical powers of the deviated beam and without deviating respectively, k the device constant, λ the wavelength in the air and P_{RF} the power of electric drive.

The Bragg condition would imply that there is only one value of the deflection angle $\theta = 2\theta_D$ allowed, but this is based on the assumption that the acoustic wave fronts are plane waves, that is, infinitely wide , which is only approximately true in practice. If the acoustic beam is of maximum width of first order for the Bragg condition $n = 1$, the serrated will be the dispersed condition with scatter angle $m\theta$, where m corresponds to the order [10].

3. Experimental set-up

Within the AOM the acoustic wave is provided by a radio frequency (RF) signal to the AOM controlled by a driver. This Driver is constituted by three components, a controlled voltage oscillator (VCO), a variable voltage altenuator (VVA) and a radiofrequency applicator [11].

The VCO provides a sine wave RF signal, the RF output frequency is determined by an applied control voltage and varies linearly with it. The VVA attenuates the output of the VCO, the degree of attenuation is controlled by varying the control voltage applied to the VVA. The amplifier extends the output of the VVA, so that the RF output is sufficient to control the AOM. The response of the AOM varies with the frequency and amplitude of the input RF signal [12].

The configuration of the experiment we used can be see it in the Figure 4 consists of an infrared laser beam that passes through a pair of mirrors adjusted ninety degrees with respect to the beam, followed by light passing through the modulator which is controlled by a driver and diffracted, finally they detect the diffracted beams of the modulator and proceed to the characterization.

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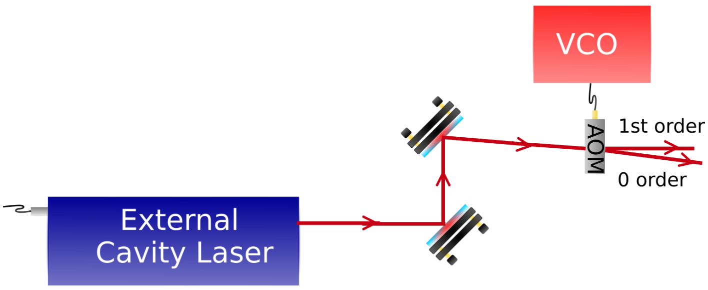
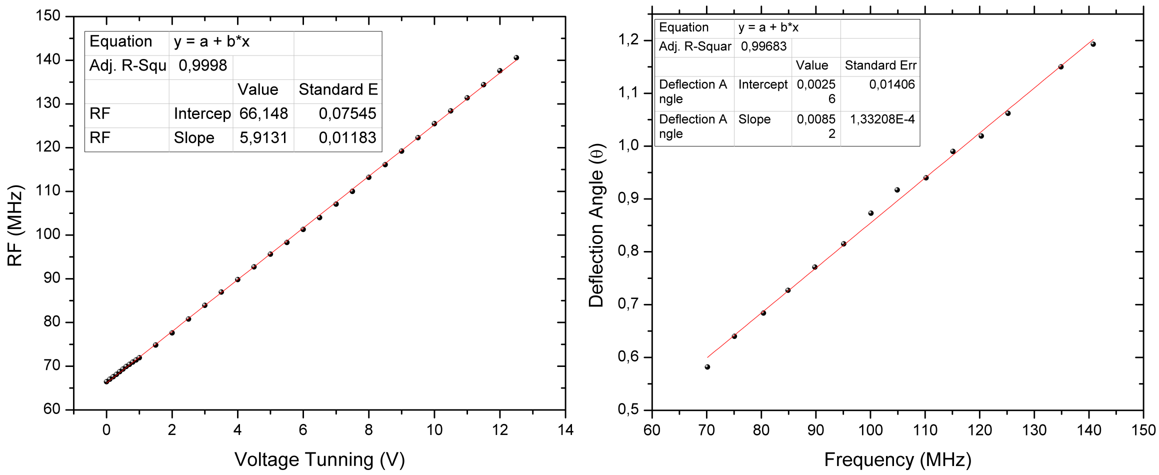


Figure 4. Experimental set-up.

4. Experimental results

After the successfully configuration, we obtained a calibration curve of the driver against the AOM. The main goal was to find the linear relationship that predicts the acousto-optic principle between the radiofrequency output and the input voltage; plus, a deflection angle as a function of frequency curve (See Figure 5) [11].



(a) (b)

Figure 5. VCO characterization. (a) Radio frequency response according to voltage tuning, and (b) deflection angle as a function of modulation frequency.

Figure 5(a) shows the linear behavior of the radiofrequency as a function of the input voltage and Figure 5(b) shows a deflection angle shift as a function of frequency.

Following a previous alignment of the system, we proceeded to optimize the beam profile taking into account the acoustic frequency supplied to the modulator. The following figures show the experimental results.

Figure 6 and Figure 7 show the response of the beam profile to a frequency modulation above the central frequency of the modulator. It can be seen how the first order (upper profile in both figures) of the beam diffracted in intensity compared to the zero order is favored.

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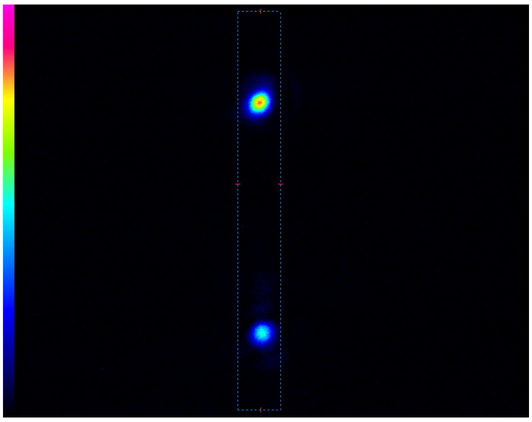

Figure 6. 2D profile of the beam modulated at high frequency.

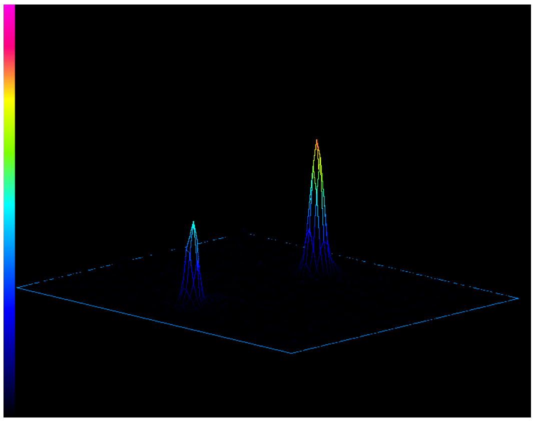

Figure 7. 3D profile of the beam modulated at high frequency.

Taking as a modulation frequency a value close to 100 MHz the center frequency of the modulator; it was observed (Figure 8 and Figure 9) how the diffracted beam is divided into two approximately equal parts, corresponding to the deflection of the beam in zero order and order one with similar characteristics. Important application when looking for equitable deviation of the laser beam in an experimental setup.

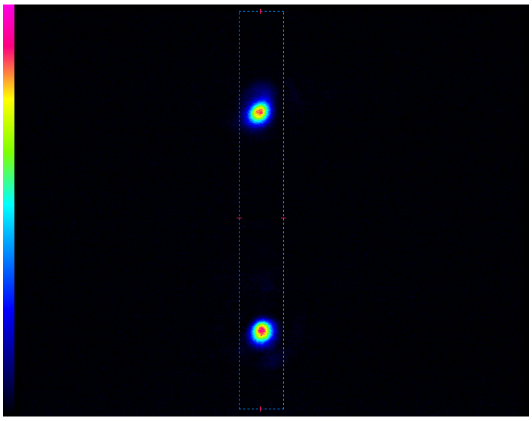

Figure 8. 2D profile beam modulated frequency close to the center.

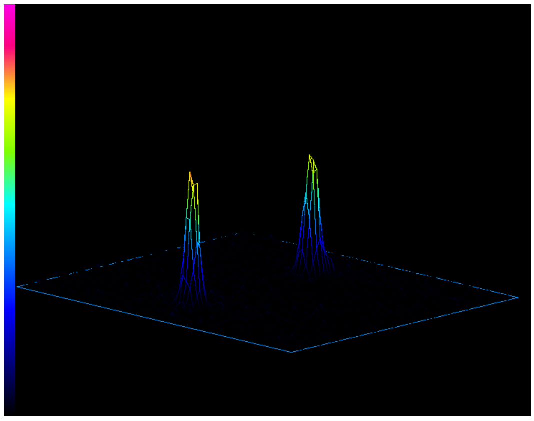

Figure 9. 3D profile beam modulated frequency close to the center.

Finally, in the Figure 10 and Figure 11, the diffraction of the laser beam at a modulation frequency below the center frequency is shown. It is well known that zero order is favored in intensity and order one has a lower percentage of this attribute, as predicted by the acousto-optic principle.

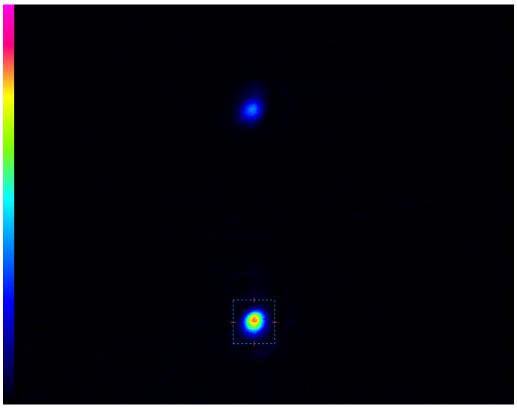

Figure 10. 2D profile of the beam modulated at low frequency.

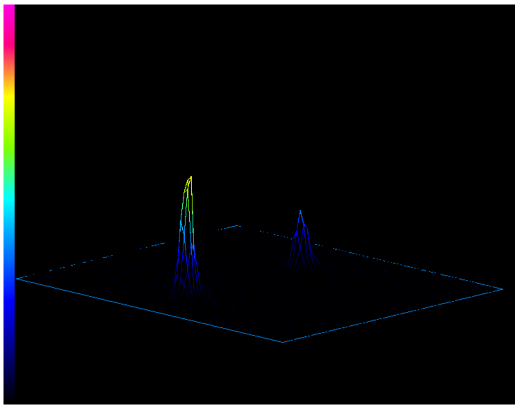

Figure 11. 3D profile of the beam modulated at low frequency.

5. Conclusions

This work describes the temporal and spatial characterization of an acousto-optic modulator working on 785 nm (near IR region). It is concluded that there is a linear relationship between the RF signal and the deflection angle. In addition, a relationship was established between the VCO voltage and the modulator frequency. On the other hand, it is established that there is no variation in the beam profile (at the output of the modulator) when varying the parameters.

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