Practical course experiment 08: Acousto-optical effect

February 19, 2024

Acousto-optical modulators (AOMs) are used in a variety of experiments or devices that work with laser light. AOMs are used to control the intensity of a light beam, to induce a defined shift in the light frequency or a targeted deflection of the light beam. This experiment is intended to illustrate the principle of operation and characteristics of an AOM.

1 Important notes

The following safety instructions must be observed when carrying out the experiment:

1. Never look directly into the laser beam!
2. Take off watches, jewellery etc. on fingers, hands and forearms before starting the experiment to avoid uncontrolled reflections!
3. The acousto-optical modulator can be damaged by excessive RF input power, please observe the maximum specifications.
4. The RF power amplifier used must never be operated without a load, otherwise it may be damaged.

2 Operating principle

The operating principle of an AOM is based on Bragg diffraction. Light of a plane wave with wavelength λ is split at a grating structure with line spacing λ with the angle of incidence θ_i into several orders n with angle of reflection θ_n, for which the Bragg equation

$$n\lambda = \lambda(\sin(\theta_n) - sin(\theta_i)) \tag{1}$$

applies. The case $n = 0$ results in $\theta_n = \theta_i$ and describes the part of the beam that is not diffracted (0th order). For the refraction of optical waves on sound waves, the conservation of momentum and energy results in $\theta_n = -\theta_i$ [1] and thus in good approximation

$$n\lambda = 2\lambda\sin(\theta_i) \tag{2}$$

The total deflection angle $\Theta = 2\theta_B$ between 0th and 1st order of an AOM now results in

$$\Theta \approx \frac{\lambda}{\lambda} = \frac{\lambda f_{RF}}{V_s} \tag{3}$$

with f_{RF} the RF frequency and V_s the speed of sound in the crystal. Conservation of momentum and energy also require a change in the laser frequency of the nth order to

$$\omega_n = \omega_L + n\omega_{RF} \tag{4}$$

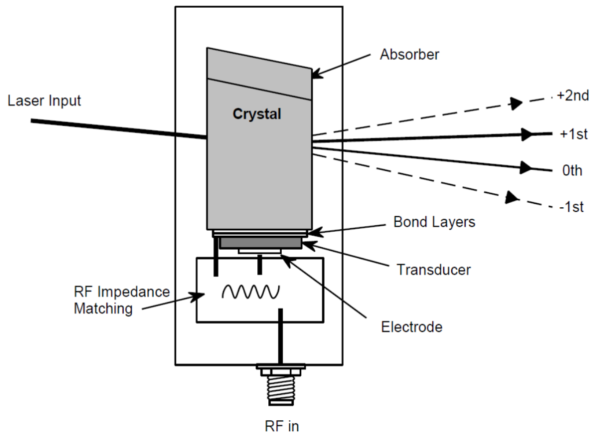

Figure 1: **Internal structure of an AOM**. Graphic taken from [2]

Fig. 1 schematically shows the internal structure of an AOM. The input RF signal is transmitted via an electronic matching circuit to a piezo transducer, which generates sound waves in the AOM crystal. These sound waves are nothing more than density changes in the medium, which lead to a periodic refractive index change. These waves pass through the crystal and are absorbed at the other end. A laser beam at the correct angle of incidence (Bragg condition) is split into several diffraction orders. With optimum coupling and moderate RF power, the 0th and 1st orders are by far the strongest components.

The diffraction efficiency $\varepsilon = P_1/P_{out}$, defined as the relative intensity between first order and total intensity, depends mainly on 2 parameters, the error in the Bragg angle and the power of the RF frequency [3]. As a good approximation, the dependence on the normalised RF power $P = P_{RF}/P_{sat}$ results in

$$\varepsilon \sim \sin^2\left(\frac{\pi}{2}\sqrt{P}\right) \tag{5}$$

and the dependence on an error in the Bragg angle as a function of the normalised angular error $\Delta = \delta/\theta_B$ or the normalised frequency detuning $F = f/f_0$ to

$$\varepsilon \sim \mathrm{sinc}^2\left(\frac{Q}{4}\Delta\right) \quad \text{or} \quad \varepsilon \sim \mathrm{sinc}^2\left(\frac{Q}{4}F(1-F)\right) \quad (6)$$

with the saturation power P_{sat} and the quality factor Q. Both factors depend on the structure and material of the AOM.

3 Experimental setup and measurements to be performed

The experimental setup consists of a HeNe laser at a wavelength of $\lambda = 632.8\,\mathrm{nm}$, which is directed onto the AOM via 2 mirrors. After the AOM, either the angular distance between the two orders or the power of the two orders is recorded using an optical power meter at a sufficiently large distance to allow separation of the 0th and 1st order.

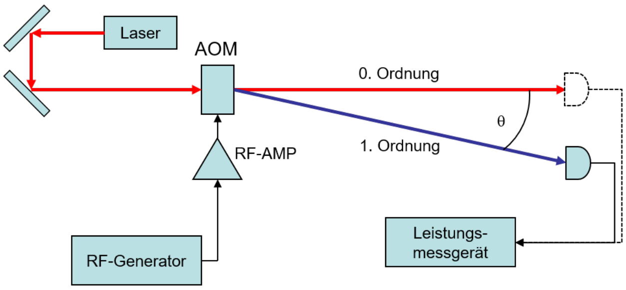

Figure 2: **Experimental setup**

3.1 Measurement of the electronic components and the optimum Bragg angle

In the first measurement, the optimum Bragg angle is to be set and determined. First calculate the values to be set in mVpp for the output powers 500 mW, 1 W and 2 W using Ref. [4] so that you always have them to hand for the subsequent measurements.

The AOM is now operated at its central RF frequency (80MHz) and with 1 W power. After coupling the beam in principle, the angle of the AOM is optimised so that the power in the 1st order is maximised using the power meter. At a sufficiently large distance (after deflection via two additional mirrors), the distance between 0th and 1st order is measured, from which the optimum Bragg angle for 80 MHz is determined and compared with the specifications from the data sheet [5].

3.2 Measurement of the intensity dependence and determination of the saturation power

First determine the total power of the light before and after the AOM without applying RF power and calculate the insertion loss $IL = 1 - P_{out}/P_{in}$. Now tune the RF power from 0 to 2 W and record the power of the 0th and 1st order. Calculate ε as a function of the power and compare the measurement with the theory. Determine the saturation power P_{sat} using a suitable fit.

3.3 Measurement of the frequency dependence and determination of the quality factor

Before the measurement, the RF power must be reduced to approx. 500 mW. Now vary the RF frequency of the AOM around its design value and again record the 1st order power and the 0th and 1st order spacing. Stay in a range between $60-100\,\mathrm{MHz}$ and select a sensible step size (test the sensitivity to frequency changes beforehand)! Compare the frequency dependence of ε and the Bragg angle θ_B obtained from the measurement with the theory and determine the quality factor experimentally using a suitable fit.

3.4 Measurement of the angle dependence and comparison of the quality factor

Now the AOM is operated with its central RF frequency (80 MHz) again! Adjust the angle of the AOM by its optimum value in a range of $\pm 1^\circ$ and again record the 1st order power. Again, select a reasonable step size (test the sensitivity to angle changes before the actual measurement)! Compare the measurement with the theory and check whether the quality factor in this measurement matches that from the previous measurement.

3.5 Measurement of the angular dependence of the maximum diffraction efficiency

Before the measurement, the RF power must be reduced to approx. 500 mW. Now the RF frequency of the AOM is varied again in the range of $60-100\,\mathrm{MHz}$, but this time the Bragg angle is readjusted and optimised at each frequency. Record the 1st order power again.

4 Report

The report should contain the following elements

- Theory of the acousto-optic modulator (figure, most important relationships)
- Experimental setup and components used (briefly)
- Evaluation and discussion of the diffraction efficiency ε as a function of the RF power, as a function of the RF frequency and as a function of the angular error Δ
- Evaluation and discussion of the values to be determined IL, θ_B (at 80 MHz), P_{sat} and Q including error specification

The theory should contain the basics and explanations so that all graphs in the protocol can be understood, i.e. it must be clearly explained why for example an error in the Bragg angle leads to a reduction in diffraction efficiency.

5 Preparation

For preparation, other sources must be used in addition to these brief exercise instructions. Refs. [2],[3],[4],[5] are available via OLAT, Ref. [1] can be downloaded as an ebook via the university network (or VPN). The preparation is sufficient if the following questions can be answered satisfactorily (i.e. including the most important formulas and with the help of illustrations)

- Where does the Bragg condition come from?
- How does an AOM work?
- Why does the diffraction efficiency depend on the RF power?
- Why does Bragg diffraction also work close to the ideal Bragg angle?
- Where does the limitation of the RF bandwidth of an AOM come from?
- What is the qualitative difference between sending a collimated or a focussed laser beam into the AOM?

References

[1] Fundamentals of Photonics, Saleh, Bahaa E. A and Teich, Malvin Carl, (2019), Chapter 20 ebook

[2] Application Note AN0510 ISOMET (OLAT)

[3] Application Note IM1022 ISOMET (OLAT)

[4] ZHL-1-2W+ Datasheet (OLAT)

[5] Gootch and Housego 3080-125 Datasheet (OLAT)