Acousto-Optic Modulators Lab

A photoelastic material changes its refractive index in the presence of mechanical stress. Let's say that there is a mechanical stress described by $s = S_0 \cos(\Omega t - \vec{K} \cdot \vec{r})$, where S_0 is the maximum strain, Ω is the acoustic angular frequency, $K=2\pi/\Lambda$ is the acoustic wavenumber, Λ is the acoustic wavelength, and *r* is the propagation direction. With this *s*, the photoelastic material response is

$$\Delta n = -\frac{1}{2} p n_0^{\,3} S_0 \cos(\Omega t - \vec{K} \cdot \vec{r}),$$

where *p* is the photoelastic response coefficient, and n_0 is the unperturbed index of refraction.

A device called an acoustic-optic modulator (AOM) takes advantage of this phenomenon in order to deflect light. In an acousto-optic modulator, a piezoelectric transducer "bangs" against a photoelastic material generating a longitudinal wave in the material. This longitudinal wave compresses and stretches the material and results in a periodic index structure (see Fig 1).

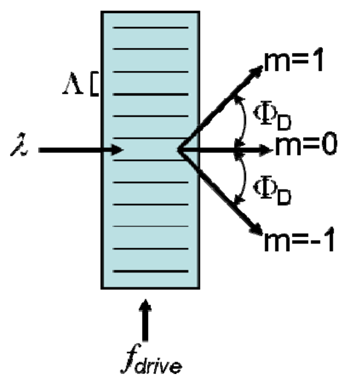

Figure 1

Schematic of an acousto-optic modulator. λ is the wavelength of light, Λ is the acoustic wavelength in the crystal, f_{drive} is the frequency applied to the transducers that create the acoustic wave, m refers to the order the light is diffracted into, and Φ_D is the angle of the deflected optical beams. Although three orders are shown here, many more orders can be produced.

When light interacts with the acoustic wave, the light is deflected according to $m\lambda = \Lambda \sin\theta_m$ assuming normal incidence, where θ_m is the angle associated with the m^{th} order. To get an intuitive understanding of why this makes sense, we can think of the interaction is two ways. First, light traveling through the region of the longitudinal wave sees a transmission phase grating (e.g., a sinusoidal variation in the index of refraction) and scatters off of it like a diffraction grating. Another way to think about the interaction is as a collision between the acoustic wave and the beam of light. Because the collision must obey conservation of energy and momentum, the energy of the lightwave shifts slightly, resulting in a change in the frequency of the light, and the direction of the beam is deflected because of the momentum kick the photon receives from the acoustic wave.

Depending on how the light wave is oriented with respect to the acoustic wave, the deflection will be either with or against the direction of the acoustic wave and the frequency of the light is either up-shifted or down-shifted by the acoustic frequency accordingly
Whether the AOM produces a few orders or many orders depends on whether the AOM is being used in the Bragg or Raman-Nath Regimes. The Raman-Nath Parameter Q is defined as

$$Q = \frac{k_a w}{k_0} \qquad [1]$$

where k_a is the wave number of the acoustic wave, k_0 is the wave number of the optic wave and w is the diameter of the acoustic wave. When Q is small compared to unity the modulator is operating in the Raman-Nath regime and produces many orders. When Q is large compared to unity, the modulator is in the Bragg regime and the modulator produces only 2 orders (i.e., m=0 and m= +1 or m= -1). In general the longer/greater the interaction of the optical wave with the acoustic wave, the more Bragg-like the interaction.

When operating in the Bragg regime if the angle of incidence θ satisfies

$$\sin\theta = \frac{\lambda}{2\Lambda} \qquad [1]$$

where λ is the optical wavelength, $\Lambda = v/f_{drive}$ is the acoustic wavelength in the material, and v is the acoustic velocity in the medium, then the incident beam satisfies the Bragg condition for constructive interference and the undeflected beam is eliminated. That is, all of the light is diffracted.

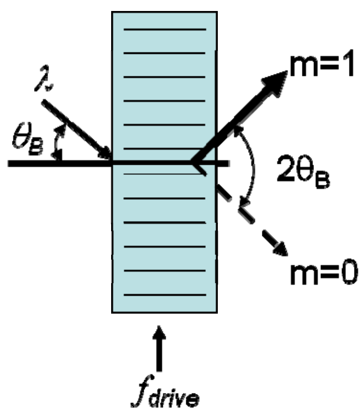

Figure 2

Schematic of set-up for Bragg condition. θ_B is the Bragg angle. Notice, there is no light going into the m=0 order.

An AOM can be used as either an amplitude modulator or a deflector. As an amplitude modulator, the amplitude of the drive signal varies in time, this causes the amount of optical power in the various orders to vary in time. This configuration is often used to tune lasers to the precise atomic transitions necessary for cooling and trapping atoms. When used as a deflector, the frequency of the modulator changes in time. This changes the angular spacing of orders. This configuration is often used as a switch.

Goals:

1) Align an AOM in a laser
2) Determine how to control the output of the AOM driver.
3) Measure/Verify characteristic parameters of the AOM.

Equipment:

- HeNe Laser
- Periscope (optional)
- Acousto-optic modulator on kinematic mount
- AOM manual
- Several frequency generators
- AOM Driver
- Oscilloscope

AOM Activities

1. Get acquainted with the AOM driver. Use the function generator as the input and observe what happens to the output of the AOM driver. What do the various knobs do? What does the output signal look like? What range of frequencies does it operate at? What amplitudes does it output? (Note: Before you connect the function generator, look in the manual to determine the maximum input voltage.)

2. Discuss with your lab mates what measurements you want to make and what experiment(s) you want to do. Draw your set-up(s). Describe your method(s). What are your hypotheses? During your lab checkout, present at least one <u>quantitative</u> analysis to determine a fundamental characteristic of the modulator. Be sure to include error analysis. The remainder of your investigations may be either quantitative or qualitative.

   Here are some things you can look at:

   What material is your AOM made of?
   How does beam deflection depend on drive frequency?
   How does intensity in the various orders vary with drive amplitude?
   Can you find the Bragg angle?
   Does polarization of the light matter?
   Can you make the AOM work in the Raman-Nath Regime? Bragg Regime?
   What happens when you FM and/of AM modulate the AOM?

3. Keep a careful record of your explorations. Do as many as you can in the time allotted.

Resources

Pedrotti Section 24.5
Saleh Chapter 20