EOM electro-optical modulator

AOM acousto-optical modulator

AOD acousto-optical deflector

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Spin selective imaging of ground state potassium atoms

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Abstract

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Zusammenfassung

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The concepts of our ultracold atom experiment were highlighted in Chapter 2, most importantly, coherent laser systems are used to modify the state of potassium atoms, which allows to induce interactions between the atoms and image them onto a camera. Having control over the electromagnetic waves by means of electronically controlled light modulators therefore gives direct control over the atomic system at each step of an experimental run. Two important components are highlighted in the following, these are electro-optical modulators (EOMs) and acousto-optical modulators (AOMs).

3.1 Electro-optical modulators

ref fundamentals of photonics somewhere

Materials can change their refractive index by being exposed to an electric field. In EOMs, this is generally a non-linear crystal connected to two electrodes. There are two prominent electro-optical effects which need to be distinguished. If the refractive index changes linearly with the electric field, the effect is called Pockels effect and the EOM is called a pockels cell. However if it changes with the square of the electric field, the effect is called Kerr effect. For this thesis, two Pockels cells from Leysop Ltd. were studied and therefore we will only discuss the pockels effect after going through some basic polarization theory.

3.1.1 Polarization

Amongst frequency and amplitude, there is another parameter that can generally be affected in electromagnetic waves, which is the polarization. The polarization is the orientation of the wave in space. In general, a wave travelling along the z-axis can be oriented somewhere in the x-y plane. Therefore, writing the electromagnetic field in this basis takes the following form:

$$E(\mathbf{x}, t) = E_x cos\left(kx - wt + \phi_x\right) \mathbf{e_x} + E_y cos\left(ky - wt + \phi_y\right) \mathbf{e_y}. \tag{3.1}$$

Here, k and w refer to the wave number and frequency respectively. Depending on the amplitudes E_x and E_y and the phases ϕ_x and ϕ_y, the wave can be in different polarization states. If it is not possible to write the wave in this basis, the light is unpolarized. Otherwise, it is **linear**, when either one of the amplitudes E_x or E_y is zero or when the phase difference $\Delta\phi = \phi_x - \phi_y$ evaluates to 0 or π. It is **circular**, when the phase difference $\Delta\phi = \pm\pi/2$ and the amplitudes are the same, $E_x = E_y$. In any other case, the wave is **elliptically** polarized.

From this point, we can see how to create a device that modifies the polarization. We can do this by retarding one axis stronger than another. Given a material with two refractive indices n_x and n_y along the axes x and y, we then get the phase shifts:

$$\phi_x(z) = k_0 n_x z \tag{3.2}$$

$$\phi_y(z) = k_0 n_y z \tag{3.3}$$

where k_0 is the free space wave vector of the light. Then a device that retards the phase difference $\Delta\phi$ by $\pi/2$, which is a quarter of the wavelength, can change linearly polarized light to circularly polarized light (or vice-versa) and is therefore called a $\lambda/4$ waveplate. Similarily, if the phase difference is changed by $\Delta\phi = \pi$, or a half wavelength, then we can turn linear polarization around a given axis or change the orientation of circularly polarized light. This is then called a $\lambda/2$ waveplate.

3.1.2 Pockels effect

The derivation of the pockels effect is fairly straightforward and as such, we follow the argumentation from the book Fundamentals of Photonics .

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Knowing that the refractive index n of the crystal in the pockels cell depends on the electric field, we can write it as $n(E)$. Applying a taylor expansion, we get the following expression:

$$n(E) = n_0 + \frac{dn}{dE}E + \mathcal{O}(E^2) \tag{3.4}$$

As was motivated before in Section 3.1, the pockels effect is the linear dependence of the refractive index to the electric field, therefore higher orders are neglected. To write the expression in terms of a more physically relevant quantity, we need to look at the electric impermeability η and its error $\Delta\eta$:

$$\eta = \frac{1}{n_0^2} \tag{3.5}$$

$$\Delta\eta = \frac{d\eta}{dn_0}\Delta n = -\frac{2}{n_0^3}\frac{dn}{dE}E = \mathfrak{r}E. \tag{3.6}$$

This results in the quantity $\mathfrak{r} = -\frac{2}{n_0^3}\frac{dn}{dE}$, which is called the Pockels coefficient given in units of $\mathrm{m\,V^{-1}}$. It can be measured by evaluating the refractive index of the material:

$$n(E) = n_0 - \frac{1}{2}\mathfrak{r}n_0^3E. \tag{3.7}$$

The pockels cells in this application act as dynamic wave retarders, therefore with the results from section 3.1.1, we can tune the phase difference $\Delta\phi = \phi_x - \phi_y$ along the axes x and y by applying an electric field.

We can see the effect on the phase difference by combining 3.1.1 and 3.1.2:

$$\begin{aligned}
\phi &= k_0Ln && (3.8)\\
&= k_0Ln_0 - \frac{k_0}{2}L\mathfrak{r}n_0^3E && (3.9)\\
&= \phi_0 - \frac{k_0}{2}L\mathfrak{r}n_0^3E && (3.10)\\
&= \phi_0 - \frac{\pi}{\lambda_0}L\mathfrak{r}n_0^3E && (3.11)\\
& && (3.12)
\end{aligned}$$

where the relation $k_0 = 2\pi/\lambda_0$ of the wave number was used.

It is now instructive to calculate the phase difference, which gives information about the change in polarization. The relations for the refractive indices in the two axis basis are labeled as:

$$n_x(E) = n_{0,x} - \frac{1}{2}\mathfrak{r}_x n_{0,x}^3 E \tag{3.13}$$
$$n_y(E) = n_{0,y} - \frac{1}{2}\mathfrak{r}_y n_{0,y}^3 E \tag{3.14}$$

and then the phase difference becomes:

$$\Delta\phi = \phi_{0,x} - \phi_{0,y} - \frac{\pi}{\lambda_0} EL \left(\mathfrak{r}_x n_x^3 - \mathfrak{r}_y n_y^3\right) \tag{3.15}$$
$$\Delta\phi = \Delta\phi_0 - \frac{\pi}{\lambda_0} EL \left(\mathfrak{r}_x n_x^3 - \mathfrak{r}_y n_y^3\right). \tag{3.16}$$

The electric field is generated by applying a voltage V to two electrodes that are separated by a distance d and therefore $E = V/d$. We can then define a half-wave voltage V_π:

$$V_\pi = \frac{d}{L} \frac{\lambda_0}{\mathfrak{r}_x n_x^3 - \mathfrak{r}_y n_y^3} \tag{3.17}$$

and the phase difference becomes:

$$\Delta\phi = \Delta\phi_0 - \pi \frac{V}{V_\pi}. \tag{3.18}$$

With this it is clear, that applying the voltage V_π, the pockels cell will act as a lambda-half waveplate.

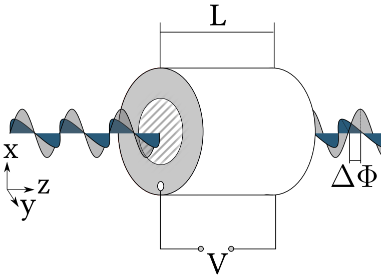

Figure 3.1: Schematic view of light passing through an EOM. The electrodes are positioned on the front and back side of the modulator, the same faces the light enters and exits.

3.1.3 Theory

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Statement of Authorship

I herewith declare that this thesis was solely composed by myself and that it constitutes my own work unless otherwise acknowledged in the text. I confirm that any quotes, arguments or concepts developed by another author and all sources of information are referenced throughout the thesis. This work has not been accepted in any previous application for a degree.

Munich, October 16, 2020

Signature