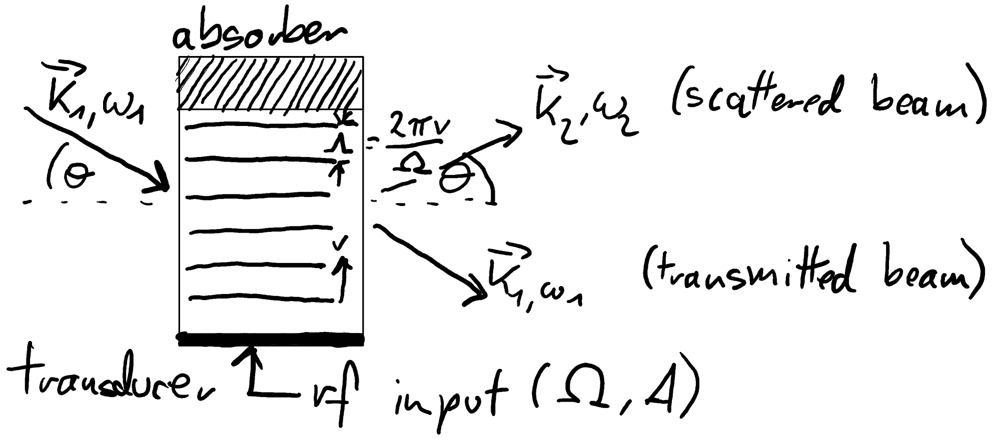
AOM + EOM

Donnerstag, 29. Juni 2023 10:44

AOM (acousto-optical modulator)



Materials: Ge, TeO_2, crystalline quartz

Example: TeO_2

$v = 4.2 \frac{mm}{\mu s}$

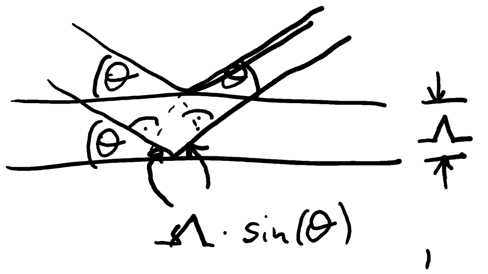
$\Omega = 2\pi \cdot 110\,MHz$

$\Lambda = 38.2\,\mu m$

$\lambda = 671\,nm \quad \Rightarrow \theta = 0.5^\circ$

$t_{rise/fall} = 18\,ns$

Bragg condition for scattering



$$\Rightarrow \Delta = 2 \cdot \Lambda \sin(\theta) \overset{!}{=} \lambda$$

2nd quantization: Phonon $\vec{q}$ moves through crystal

Brillouin scattering: Photon can absorb $\vec{q} \Rightarrow \vec{k}_2 = \vec{k}_1 + \vec{q}$, $\omega_2 = \omega_1 + \Omega$

or emit $\vec{q} \Rightarrow \vec{k}_2 = \vec{k}_1 - \vec{q}$, $\omega_2 = \omega_1 - \Omega$

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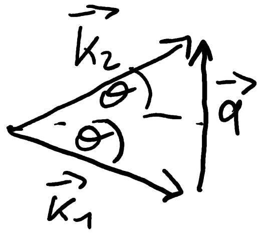
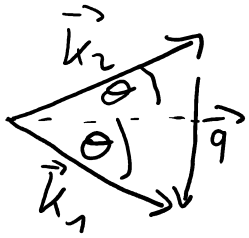




higher orders are also possible.

Application:

- frequency shift
- deflect beam
- amplitude modulation (change of amplitude to change beam intensity)
- fast switch

EOM (electrooptic modulator)

linear electrooptic effect (Pockels effect)

Anisotropic material

$$\vec{D} = \varepsilon_0 \begin{bmatrix} \varepsilon_{xx} & \varepsilon_{xy} & \varepsilon_{xz} \\ \varepsilon_{yx} & \varepsilon_{yy} & \varepsilon \\ \varepsilon_{zx} & \varepsilon & \varepsilon_{zz} \end{bmatrix} \vec{E}$$

for lossless, non-optically active media $\Rightarrow \varepsilon_{ij}$ = real, symmetric

$\Rightarrow$ choose diagonal matrix $\begin{bmatrix} \varepsilon_x & & \\ & \varepsilon_y & \\ & & \varepsilon_z \end{bmatrix}$

Consider energy density per Volume:

$$U = \frac{1}{2} \vec{D} \circ \vec{E} = \frac{1}{2\varepsilon_0} \left[\frac{D_x^2}{\varepsilon_x} + \frac{D_y^2}{\varepsilon_y} + \frac{D_z^2}{\varepsilon_z} \right]$$

Define $X = \sqrt{\frac{1}{\ldots}}\, D$

Define $X = \sqrt{\frac{1}{2\varepsilon_0 n}} D_x$

Y, Z accordingly

$$\Rightarrow \frac{X^2}{\varepsilon_X} + \frac{Y^2}{\varepsilon_Y} + \frac{Z^2}{\varepsilon_Z} = 1$$

$\Rightarrow$ Surfaces of constant energy density in $\vec{D}$ space are ellipsoids

$$\left(\frac{1}{n^2}\right)_1 x^2 + \left(\frac{1}{n^2}\right)_2 y^2 + \left(\frac{1}{n^2}\right)_3 z^2 + 2\left(\frac{1}{n^2}\right)_4 yz + 2\left(\frac{1}{n^2}\right)_5 xz + 2\left(\frac{1}{n^2}\right)_6 xy = 1$$

$$1 = \vec{x}^T \left[\frac{1}{n^2}\right] \vec{x}$$

$$\frac{1}{n^2} = \begin{pmatrix} \left(\frac{1}{n^2}\right)_1 & \left(\frac{1}{n^2}\right)_6 & \left(\frac{1}{n^2}\right)_5 \\ \left(\frac{1}{n^2}\right)_6 & \left(\frac{1}{n^2}\right)_2 & \left(\frac{1}{n^2}\right)_4 \\ \left(\frac{1}{n^2}\right)_5 & \left(\frac{1}{n^2}\right)_4 & \left(\frac{1}{n^2}\right)_3 \end{pmatrix}$$

Assume $\left(\frac{1}{n^2_{ij}}\right) = \left(\frac{1}{n^2}\right)^{(0)}_{ij} + \underline{\sum_k \varepsilon_{ijk} E_k} + \sum_{kl} s_{ijkl} E_k E_l + \dots$

r_{ijk} is the tensor describing the linear electrooptic effect

$$\begin{bmatrix} \Delta(1/n^2)_1 \\ \Delta(1/n^2)_2 \\ \Delta(1/n^2)_3 \\ \Delta(\quad)_4 \\ \Delta(\quad)_5 \\ \Delta(\quad)_6 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & \cdot & \cdot \\ r_{31} & \cdot & \cdot \\ r_{41} & \cdot & \cdot \\ r_{51} & \cdot & \cdot \\ r_{61} & \cdot & \cdot \end{bmatrix} \vec{E}$$

r_{ij} depends on the symmetry of the material

Example: Lithium Niobate ($LiNbO_3$) (3m point group)

$$r_{ij} = \begin{bmatrix} 0 & -r_{22} & r_{13} \\ 0 & r_{22} & r_{13} \\ 0 & 0 & r_{33} \\ 0 & r_{42} & 0 \\ r_{42} & 0 & 0 \\ r_{22} & 0 & 0 \end{bmatrix}$$

$r_{13} = 9.6 \frac{pm}{V}$

$r_{22} = 6.8$

$r_{33} = 30.9$

$r_{42} = 32.6$

KH_2PO_4 (Potassium Dihydrogen Phosphate) KDP

$\bar{4}2m$

$$r_{ij} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ r_{41} & 0 & 0 \\ 0 & r_{41} & 0 \\ 0 & 0 & r_{63} \end{bmatrix}$$

$r_{41} = 8.77 \frac{pm}{V}$

$r_{63} = 10.5$

$$0 \quad 0 \quad r_{63} \,]$$

Without $\vec{E}$-field: $$\frac{X^2}{n_o^2} + \frac{Y^2}{n_o^2} + \frac{Z^2}{n_e^2} = 1$$

With $\vec{E}$: $$\frac{X^2}{n_o^2} + \frac{Y^2}{n_o^2} + \frac{Z^2}{n_e^2} + 2 r_{41} E_X YZ + 2 r_{41} E_Y XZ + 2 r_{63} E_Z XY = 1$$

Assuming only z-component & $X = \frac{x-y}{\sqrt{2}}$, $Y = \frac{x+y}{\sqrt{2}}$, $Z = z$

$$\left(\frac{1}{n_o^2} + r_{63} E_z\right) x^2 + \left(\frac{1}{n_o^2} - r_{63} E_z\right) y^2 + \frac{z^2}{n_e^2} = 1$$

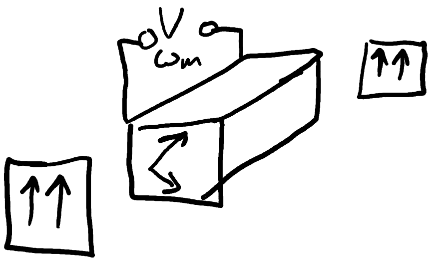
refractive indeces for x and y change differently with E_z

One polarization faster $\Rightarrow$ total pol is tilted

(compare to $\frac{\lambda}{2}$- & $\frac{\lambda}{4}$-plates)

Amplitude modulation

Pockels cell with 2 pol filters



$$\vec{E} = \vec{E}_0(t) \cdot e^{i\omega t}$$

$$\vec{E}_0(t) = \hat{e} \cdot (A_0 + \Delta A \cdot \cos(\omega_m t))$$

$$= \hat{e}\left(A_0 + \frac{\Delta A}{2}\left(e^{i\omega_m t} + e^{-i\omega_m t}\right)\right)$$

$$\vec{E} = \hat{e}\left(A_0 e^{i\omega t} + \frac{\Delta A}{2} e^{i(\omega+\omega_m)t} + \frac{\Delta A}{2} e^{i(\omega-\omega_m)t}\right)$$

carrier

2 side bands

Phase modulation

$$\vec{E}(t) = \vec{E}_0 e^{i\varphi(t)}$$

$$\varphi(t) = \omega t + \Delta\varphi \cdot \sin(\omega_m t) = \omega t + \frac{\Delta\varphi}{2i}\left(e^{i\omega_m t} - e^{-i\omega_m t}\right)$$

$$\vec{E}(t) = \vec{E}_0 \, e^{i\omega t} \cdot e^{\frac{\Delta\varphi}{2}\left(e^{i\omega_m t} - e^{-i\omega_m t}\right)}$$

$$e^{\frac{M}{2}\left(z - \frac{1}{z}\right)} = \sum_{n\in\mathbb{Z}} J_n(M)\, z^n$$

n-th Bessel function

$$= \vec{E}_0 \sum_n J_n(\Delta\varphi)\, e^{i(\omega + n\cdot\omega_m)t}$$

Carrier (n=0) & infinite sidebands

Applications:

- Laser locking (Modulation + Demodulation)
- Frequency shift (up to GHz-level)