Electro-optic Modulator

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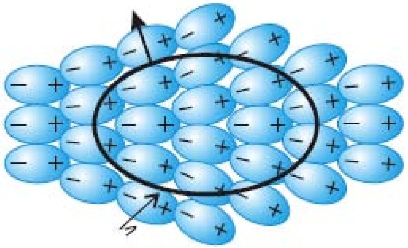
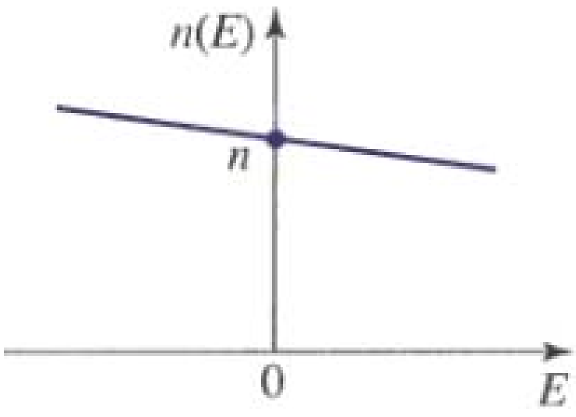
Electro optic modulator

Electro-optic Effect : Application of electric field results in redistribution of charges thus changing the refractive index of a material and thereby the effect on polarized light transmitting through it.



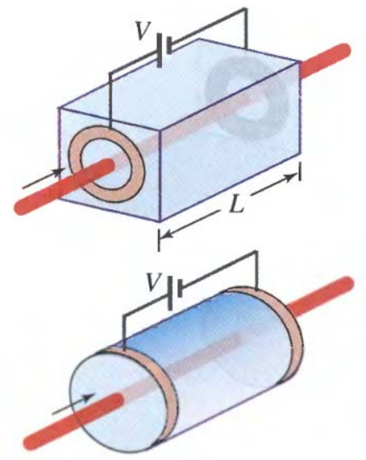
$$n(E) = n + aE + \frac{1}{2}bE^2 + \ldots$$

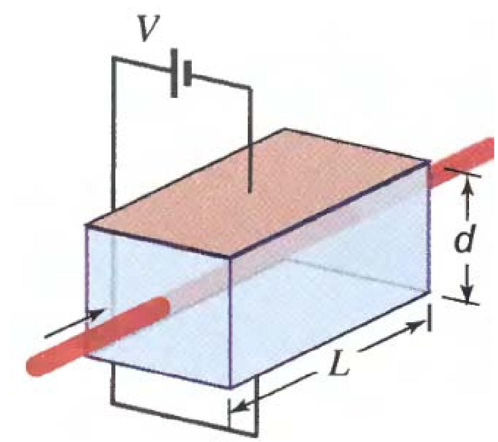
Pockels Effect : The refractive index changes linearly with the applied electric field.



Pockels Effect : the linear Electro-optic effect.

Friedrich Pockels described the linear Electro-optic effect in 1893.





Transverse

Longitudinal

Applications:

Lens of controllable focal length.

Optical scanning devices.

Controllable wave retarder.

Intensity modulator or optical switch.

Fast optical shutters.

Crystal Optics: EM Wave in Anisotropic Medium

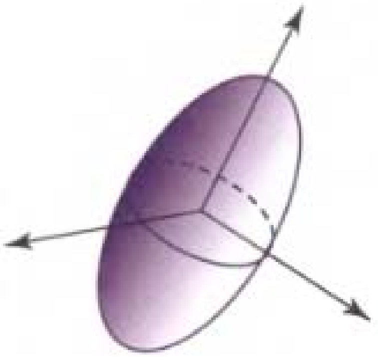
In linear anisotropic dielectric medium electric flux density is related to electric field as

$$D_i = \sum_j \varepsilon_{ij} E_j \qquad\qquad i, j = 1,2,3$$

refer to x, y, z components.

An ellipsoid is a quadratic surface, geometrical representation of a symmetric second rank tensor,

$$\sum_{ij} \varepsilon_{ij} x_i x_j = 1$$



The coordinate system for which dielectric tensor is diagonal defines the principal axes and the principal planes of the crystal, D and E are parallel

$$D_1 = \varepsilon_1 E_1 \quad , \quad D_2 = \varepsilon_2 E_2 \quad , \quad D_3 = \varepsilon_3 E_3$$

where,

$$\varepsilon_1 = \varepsilon_{11} \, , \; \varepsilon_2 = \varepsilon_{22} \; , \; \varepsilon_3 = \varepsilon_{33}$$

and

$$n_1 = \sqrt{\varepsilon_1 / \varepsilon_o} \quad , \quad n_2 = \sqrt{\varepsilon_2 / \varepsilon_o} \quad , \quad n_3 = \sqrt{\varepsilon_3 / \varepsilon_o}$$

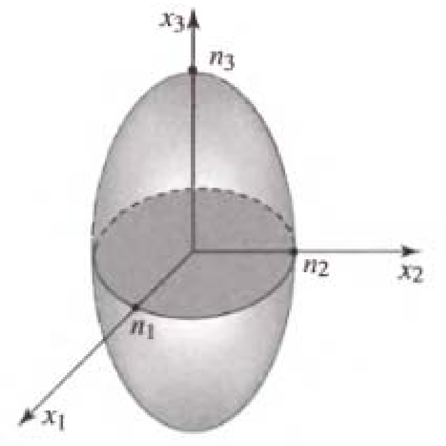
Electric impermeability tensor

$$\eta = \varepsilon_o \varepsilon^{-1}$$

is diagonal in principal coordinate system.

Index ellipsoid is the quadratic representation of the electric impermeability tensor

$$\sum_{ij} \eta_{ij} x_i x_j = 1 \qquad\qquad i, j = 1,2,3$$



If the principal axes are used as coordinate system, for convenience, $x = 1, y = 2, z = 3$

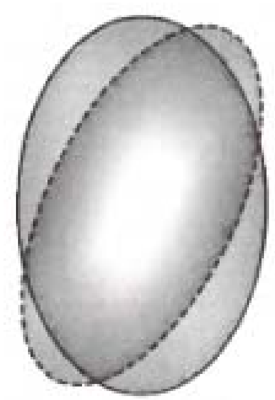
$$\frac{x^2}{n_x^2} + \frac{y^2}{n_y^2} + \frac{z^2}{n_z^2} = 1$$

Since, refractive index is a function of applied field, the optical impermeability tensor, $\eta_{ij}(E)$ is modified.

$$\Delta \eta_{ij} = \Delta(1/n^2)_{ij} = r_{ijk} E_k \qquad , \qquad k = x, y, z$$

The coefficients r_{ijk} are called the Pockels Coefficient.

Index ellipsoid is modified



$$\eta_{ij}(E)x_i x_j = 1$$

or

$$(\frac{1}{n_x^2} + r_{11k}E_k)x^2 + (\frac{1}{n_y^2} + r_{22k}E_k)y^2 + (\frac{1}{n_z^2} + r_{33k}E_k)z^2 + 2yzr_{23k}E_k + 2zxr_{13k}E_k + 2xyr_{12k}E_k = 1$$

Mixed terms; Principal axes of crystal x, y, z are no longer principal axes of index ellipsoid.

$j \backslash i$	1	2	3
1	1	6	5
2	6	2	4
3	5	4	3

Using contracted indices,

$$(\frac{1}{n_x^2} + r_{1k}E_k)x^2 + (\frac{1}{n_y^2} + r_{2k}E_k)y^2 + (\frac{1}{n_z^2} + r_{3k}E_k)z^2 + 2yzr_{4k}E_k + 2zxr_{5k}E_k + 2xyr_{6k}E_k = 1$$

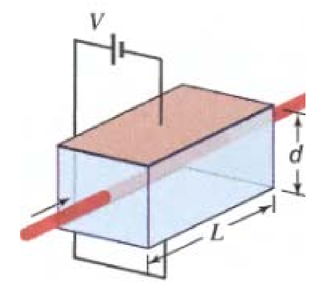
Electro-optic tensor for ADP crystal is

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

the modified index ellipsoid is

$$\frac{x^2}{n_x^2} + \frac{y^2}{n_y^2} + \frac{z^2}{n_z^2} + 2yzr_{41}E_x + 2zxr_{41}E_y + 2xyr_{63}E_z = 1$$

ADP is uniaxial and in transverse mode,

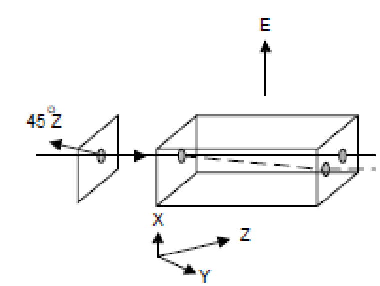


$$\frac{x^2}{n_0^2} + \frac{y^2}{n_0^2} + \frac{z^2}{n_e^2} + 2yzr_{41}E_x = 1$$

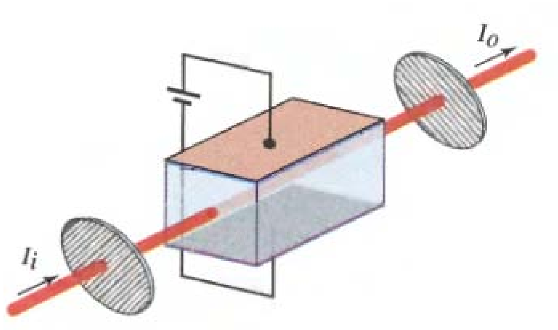
The phase retardation, Γ between normal modes is,

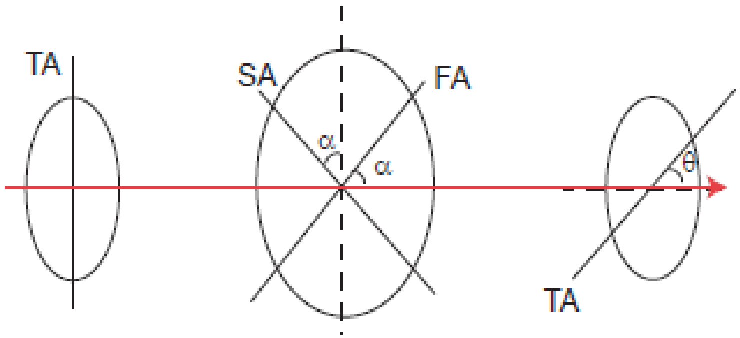
$$\Gamma = \frac{2\sqrt{2}}{(1/n_0^2 + 1/n_e^2)^{3/2}} r_{41} \frac{\pi}{\lambda} \frac{V}{d} L$$

$$\Gamma = \frac{\pi V}{V_\pi}$$



Transmission curves for Pockels cell :

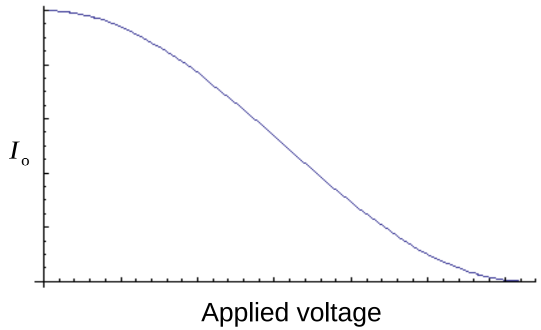




$$I_o = I_i/4\,(2 - \mathrm{Cos}[4\alpha - 2\theta] - \mathrm{Cos}[2\theta] - 2\,\mathrm{Cos}[\Gamma]\,\mathrm{Sin}[2\alpha]\,\mathrm{Sin}[2(\alpha - \theta)])$$

For, $\alpha = \pi/4$

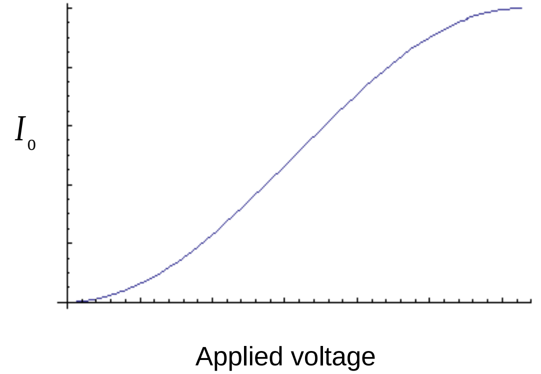
$$I_o = I_i/2\,(1 - \mathrm{Cos}\,2\theta\,\mathrm{Cos}\,\Gamma)$$



For parallel polarizer, $\theta = \pi/2$

$$I_o = I_i\,\mathrm{Cos}^2(\Gamma/2)$$

For crossed polarizer, $\theta = 0$



$$I_o = I_i\,\mathrm{Sin}^2(\Gamma/2)$$

Amplitude modulation:

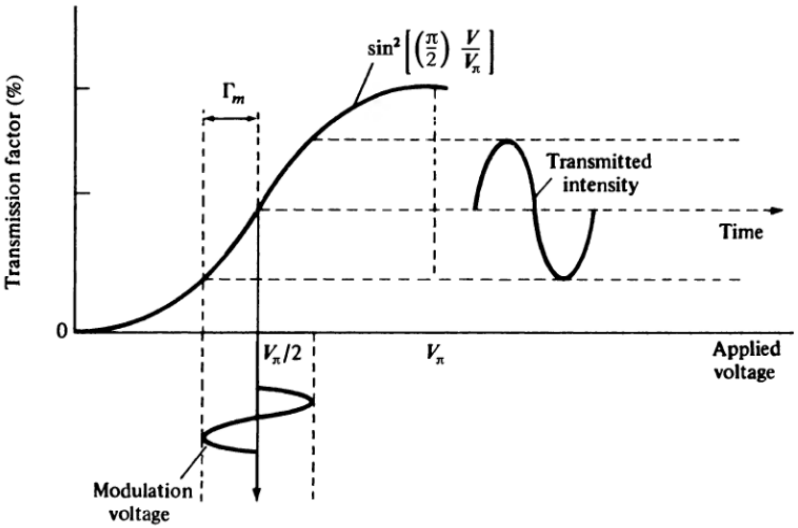
Biased at quarter wave voltage

$$I_o = I_i \, \mathrm{Sin}^2\left(\frac{1}{2}\left(\frac{\pi}{2} + \Gamma_m \mathrm{Sin}\omega_m t\right)\right)$$

$$I_o \approx \frac{I_i}{2}(1 + \Gamma_m \mathrm{Sin}\omega_m t)$$

Where,

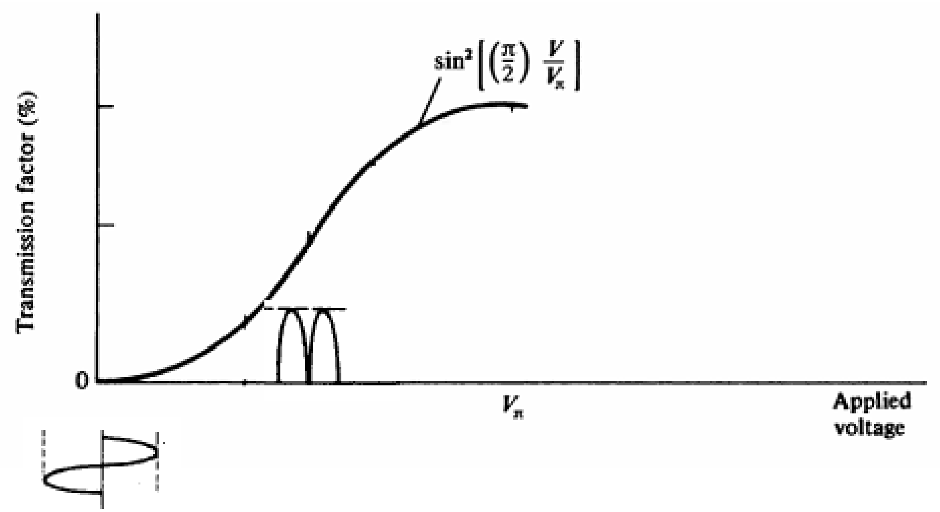
$$\Gamma_m = \pi(V_m / V_\pi)$$



Unbiased or biased at half wave voltage

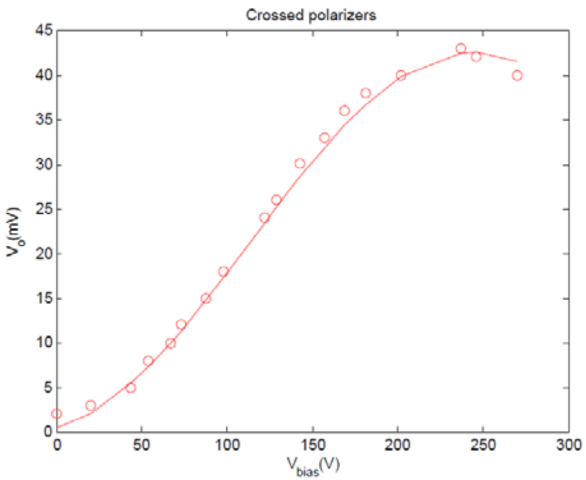
$$I_o = I_i \, \mathrm{Sin}^2\left(\frac{\pi}{2V_\pi} V_m \mathrm{Sin}\omega_m t\right)$$

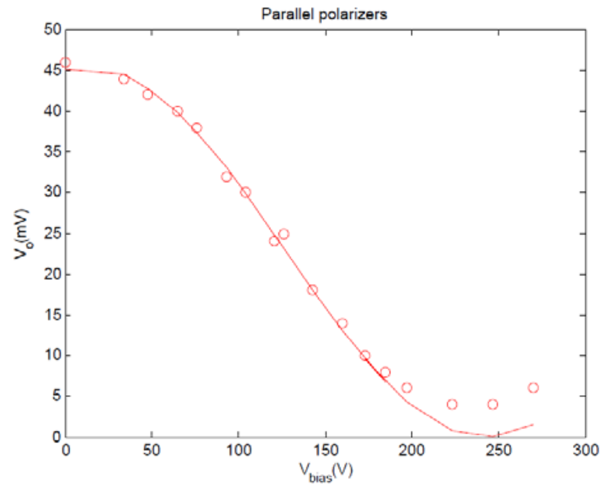
$$I_o = I_i \frac{\pi^2 V_m^2}{8V_\pi^2}(1 + \mathrm{Cos}\, 2\omega_m t)$$



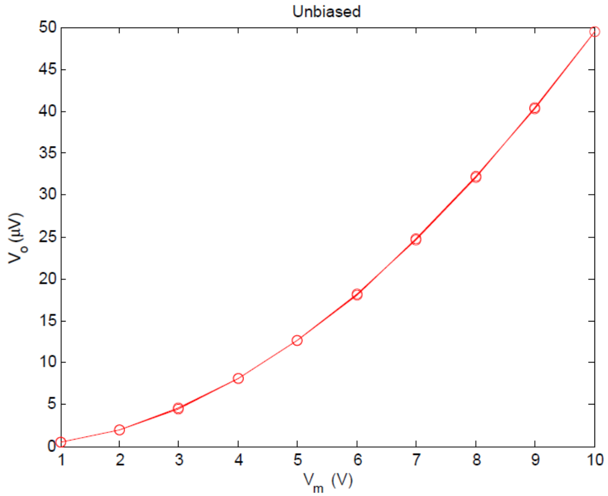
Results:

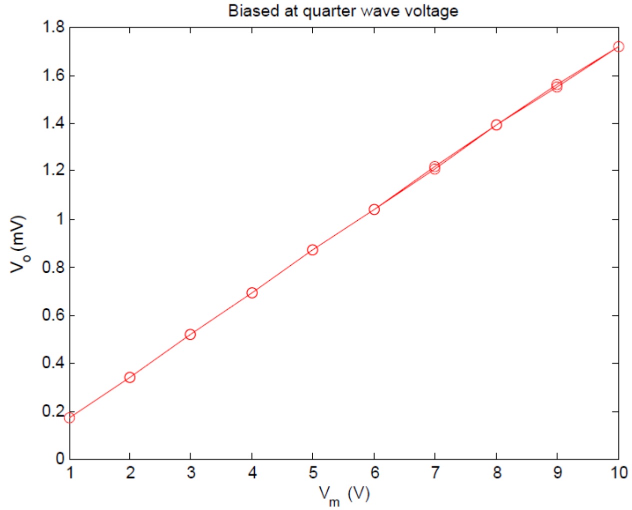
1. Transmission curves for EOM





2. Amplitude modulation





THANK YOU