MASSACHUSETTS INSTITUTE of TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.161 Modern Optics Project Laboratory

Problem Set No. 6	**Light Modulation**	Issued Thrs. 10/20/2005
Fall Term, 2005	**-**	Due Tues. 11/1/2005

Reading recommendation: Class Notes, Chapter 7; Yariv, Chapter 9. Be neat in your work!

Problem 6.1 - Transverse ADP Modulator

Consider the transverse electro-optic modulator shown below. The crystal material is Ammonium Dihydrogen Phosphate (ADP), a tetragonal $\bar{4}2$m crystal. The input light is polarized at 45 $^\circ$ to the z and y' axes for intensity modulation. The z axis is the optical axis of the crystal, and the x' and y' axes are oriented at 45 $^\circ$ to the crystallographic axes, x and y (not shown).

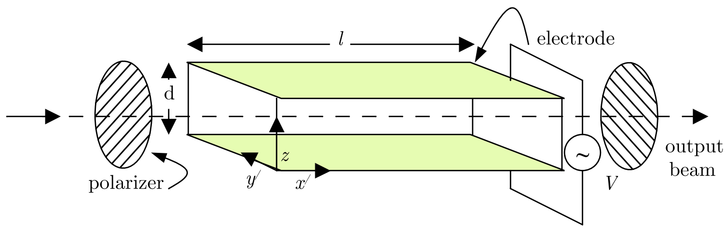


Figure 1: ADP crystal under transverse modulation

(a) For ADP with an electric field applied along is z axis, show that, in general, the indices of refraction for light polarized along x', y' and z are

$$\begin{aligned} n_{x'}(V) &\approx n_o - \frac{1}{2}n_o^3 r_{63}\frac{V}{d} \\ n_{y'}(V) &\approx n_o + \frac{1}{2}n_o^3 r_{63}\frac{V}{d} \\ n_z(V) &= n_E \end{aligned}$$

(b) For the specific modulator configuration shown above, show that the total phase retardation $\Gamma = \phi_{y'} - \phi_z$ is given by

$$\Gamma = \frac{2\pi l}{\lambda}\left\{(n_o - n_E) + \frac{n_o^3}{2} r_{63}\frac{V}{d}\right\}$$

(c) If the crystal thickness d is 2 mm, and its half-wave voltage (corresponding to $\Delta\Gamma(V_\pi) = \Gamma(V_\pi) - \Gamma(0) = \pi$) as measured in transverse operation (see figure above) is 1200 volts, what is the length of the crystal? (electro-optic coefficients and indices of refraction for ADP can be found in one of the tables of Yariv, Chap 9. Assume λ=6328Å).

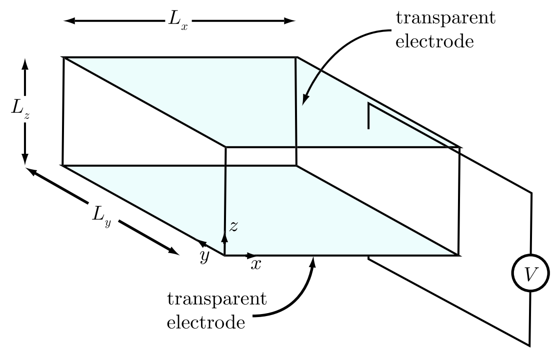
(d) Calculate the corresponding quarter-wave voltage, $\Delta\Gamma(V_{\frac{\pi}{2}})$, for transverse operation. Discuss the advantages and disadvantages of transverse vs longitudinal modulators.

Problem 6.2 - Lithium Niobate Modulator Design

The goal here is to design intensity and phase modulators for a collimated, **unpolarized** light beam of intensity, I_{in} , using the electro-optic effect in a given lithium niobate crystal. Lithium niobate is an uniaxial material ($n_x = n_y$) and its electro-optic tensor contains the following non-zero elements:

$$r_{22} = -r_{12} = -r_{61} \qquad r_{13} = r_{23} \qquad r_{42} = r_{51} \text{ and } r_{33}$$

The given crystal has transparent electrodes on the faces perpendicular to the c-axis as shown, and its dimensions are L_x, L_y and L_z. Thus, you can apply electric fields along the z-axis only. However, you can propagate the light beam to be modulated along either the x, y or z axes.



(a) First, I would like you to make a phase-only modulator but without the use of polarizers. Draw a diagram to show how you would operate the crystal to achieve this goal. For your chosen operation, what is your expression for $\Delta\Phi(V)$?

(b) Now I would like you to design an intensity modulator. Place the crystal between polarizers (not necessarily crossed), and for each of the three propagation directions, derive an expression for $I_{\text{out}}(V)/I_{\text{in}}$. Be sure to clearly specify your chosen orientation of the polarizers relative to the axes of the crystal (a diagram is required for each case).

(c) Suppose that the wavelength of the light to be modulated is $\lambda = 0.6\mu$m, and that $L_x = L_y = L_z$. Given that $n_O = 2.286, n_E = 2.200$ and that

$r_{22} = -r_{12} = -r_{61} = 6.8$ pm$/V$ (pm=pico meter= 10^{-12}m)

$r_{13} = r_{23} = 9.6$pm$/V$

$r_{42} = r_{51} = 32.6$ pm$/V$

$r_{33} = 30.9$ pm$/V$

Which of the three cases makes the most efficient intensity light modulation system in terms of intensity change per volt? What is the half wave voltage for this system? How could you significantly lower the halfwave voltage?

Problem 6.3 - Acousto-optic Modulator Power

Calculate the amount of acousto-optic power required to achieve a refractive index change of 0.0001 in a $LiNbO_3$ modulator that is 1 mm wide and 1 mm high. (see Yariv or other text book to get the numbers needed)