Menoufia University
Faculty of Electronic Engineering
Electronics and Electrical Communications Eng. Dept.
Third Year – Spring 2019

ECE 325 - Optoelectronics
Problem Set #5

Polarization of light

Textbook: S. O. Kasap, Optoelectronics and Photonics: Principles and Practices, international ed., Prentice Hall, 2012.

Chapter 6:

[P1] **6.10** - Draw a quartz Wollaston prism and clearly show and identify the directions of orthogonally polarized waves traveling through the prisms. How would you test the polarization states of the emerging rays? Consider two identical Wollaston prisms, one from calcite and the other from quartz. Which will have a greater beam-splitting ability? Explain.

[P2] **6.11** - Figure 6.44 shows the cross-section of a Glan–Foucault prism which is made of two right angle calcite prisms with a prism angle of 38.5°. Both have their optic axes parallel to each other and to the block faces as in the figure. Explain the operation of the prisms and show that the o-wave does indeed experience total internal reflection.

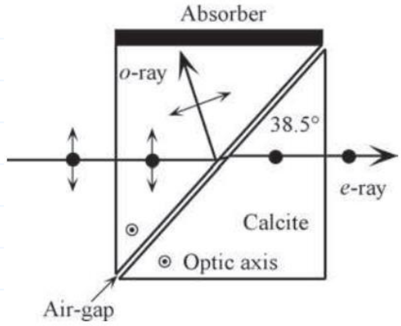

Figure 6.44 The Glan–Foucault prism provides linearly polarized light.

[P3] **6.13b** - Sketch how you would construct an LCD cell that is normally black and becomes bright upon the application of an AC voltage.

[P4] **6.14** - The LCD characterization measurements of M. Schadt and W. Helfrich reported in their paper in Applied Physics Letters in 1971 (18, 127, 1971) are summarized in Table 6.6. (a) Plot Φ vs. V_{rms}. (b) Plot T′ vs. V_{rms}. (c) What are the threshold and saturation voltages?

TABLE 6.6 **Data obtained by M. Schadt and W. Helfrich on a twisted nematic liquid crystal cell. The normalized transmission T' is the measured transmittance divided by the maximum transmittance, *i.e.*, $T(V_{\mathrm{rms}})/T_{\max}$**

V_{rms} (V)	0.17	0.98	3.00	3.57	3.97	4.49	4.90	5.30	5.99	6.99		
Φ	89.4°	89.2°	89.6°	84.5°	71.7°	52.3°	34.6°	16.9°	8.84°	2.75°		
V_{rms} (V)	0.20	1.50	3.00	3.39	3.71	4.01	4.50	5.00	5.46	6.00	6.97	7.72
T' (%)	3.41	3.41	3.41	6.83	15.1	30.1	60.0	80.1	91.8	96.2	99.6	100

[P5] **6.15** - What should be the aspect ratio d/L for the transverse LiNiO3 phase modulator in Figure 6.24 that will operate at a free-space wavelength of 1.3 μm and will provide a phase shift $\Delta\Phi$ of π (half wavelength) between the two orthogonal field components propagating through the crystal for an applied voltage of 12 V?

[P6] **6.16** - Suppose that instead of the configuration in Figure 6.25, the field is applied along the z-axis of the crystal and the light propagates along the y-axis. The z-axis is the polarization of the ordinary wave and x-axis that of the extraordinary wave. Light propagates through as ***o***- and ***e***-waves. Given that $E_a = V/d$, where d is the crystal length along z (crystal thickness), the indices are

$$n_o' \approx n_o + \frac{1}{2}n_o^3 r_{13} E_a \quad \text{and} \quad n_e' \approx n_e + \frac{1}{2}n_e^3 r_{33} E_a$$

Show that the phase difference between the ***o***- and ***e***-waves emerging from the crystal is

$$\Delta\phi = \phi_e - \phi_o = \frac{2\pi L}{\lambda}(n_e - n_o) + \frac{2\pi L}{\lambda}\left[\frac{1}{2}(n_e^3 r_{33} - n_o^3 r_{13})\right]\frac{V}{d}$$

where L is the crystal length along the y-axis.

Explain the first and second terms. How would you use two such Pockels cells to cancel the first terms in the total phase shift for the two cells?

If the light beam entering the crystal is linearly polarized in the z-direction, show that

$$\Delta\phi = \frac{2\pi n_e L}{\lambda} + \frac{2\pi L}{\lambda}\left[\frac{(n_e^3 r_{33})}{2}\right]\frac{V}{d}$$

Consider a nearly monochromatic light beam of the free-space wavelength $\lambda = 633$ nm and polarization along z-axis. Calculate the voltage V_π needed to change the output phase $\Delta\phi$ by π given a LiNbO3 crystal with $d/L = 0.01$ (see Table 6.2).

[P7] **6.17** - (a) Sketch schematically the structure of a longitudinal Pockels cell in which the applied field is along the direction of light propagation, both parallel to the z-axis (optic axis). Suggest schemes that would allow light to enter the crystal along the applied field direction.

(b) Suppose that an LiNbO3 crystal is used. LiNbO3 is uniaxial and $n_1 = n_2 = n_o$ (polarizations parallel to x and y) and $n_3 = n_e$ (polarization parallel to z). Neglecting the rotation of the axes (same principal axes in the presence of an applied field), the new ordinary refractive index is

$$n_o' \approx n_o + \frac{1}{2}n_o^3 r_{13} E_a$$

Calculate the half-wave voltage required to induce a retardation of π between the emerging and incident waves if the free-space wavelength is 1 μm. What are their polarizations? (Note: For $LiNbO_3$ at 633 nm, $n_o \approx 2.28$ and $r_{13} \approx 9 \times 10^{-12}$ m V^{-1}.)

(c) Suppose that a KDP crystal is used. KDP is uniaxial and $n_1 = n_2 = n_o$ (polarizations parallel to x and y) and $n_3 = n_e$ (polarization parallel to z). The principal axes x and y are rotated by 45° to become x' and y' as in Figure 6.23 and

$$n_1' \approx n_o - \frac{1}{2}n_o^3 r_{63} E_a \quad n_2' \approx n_o + \frac{1}{2}n_o^3 r_{63} E_a \quad \text{and} \quad n_3' = n_3 = n_e$$

Calculate the half-wave voltage required to induce a retardation of π between the emerging components of the electric field for free-space wavelength of 633 nm if, for KDP at this wavelength, $n_o \approx 1.51$ and $r_{63} \approx 10.3 \times 10^{-12}$ m V^{-1}.