Physics Department

Optical Electronics (PHL 792); II Semester 2007-08: Major

ALL QUESTIONS ARE COMPULSORY **M Marks: 40**

1. Give brief answers to the following: **(8x1.5=12)**
   a) A plane wave propagates along a direction with unit vector $\hat{\kappa} = \sqrt{3}/2\,\hat{y} + 1/2\,\hat{z}$ in a uniaxial medium. Give an expression for the unit vector along $\vec{D}$ for the extraordinary wave.
   b) A uniaxial crystal has the following non-zero electro-optic coefficients: r_{12}, r_{22} and r_{61}. Obtain the principal refractive indices of the crystal in the presence of an electric field of magnitude E pointing along the y-axis.
   c) Consider collinear codirectional interaction in lithium niobate ($n_o = 2.26$, $n_e = 2.20$) of a light wave at $\lambda_0 = 0.6$ μm propagating along the x-direction with an acoustic wave also propagating along the x-direction. Draw a vector diagram showing generation of −1 order diffraction specifying the polarization states of the input and output light waves.
   d) The refractive indeices of a medium at wavelengths of 1 μm and 0.5 μm are given by 2.16 and 2.27 respectively. What is the velocity of the nonlinear polarization generated at the frequency corresponding to the wavelength of 1 μm?
   e) The phase matched SHG efficiency of a 5 cm long KDP crystal is 1 %. For what value of Δk will the SHG efficiency become zero?
   f) Using $\chi^{(2)}$ nonlinearity, I wish to generate a wavelength of 3 μm from a laser beam of wavelength 1 μm. What process can lead to this and what other input wave you would need.
   g) Light waves at frequencies ω_0 and ω_0-$\Delta\omega$ with propagation constants k_1 and k_2 and electric fields E_1 and E_2 respectively, are incident in an optical fiber. Calculate the nonlinear polarization generated at a frequency $\omega_0 + \Delta\omega$.
   h) What is the change in phase at the output of a 1 km long fiber when the power is changed from 10 μW to 100 mW. Assume the area of the light beam propagating in the fiber to be 50 μm^2 and $n_2 = 3 \times 10^{-20}$ m^2/W. Neglect fiber loss.

2. An electric field E_z is applied along the z – axis of $LiNbO_3$ crystal of length L.
   a) Write down the equation of the index ellipsoid in the presence of the electric field.
   b) For light polarized along x and propagating along z, obtain an expression for the voltage required to induce a phase shift of π.
   c) If the input wave is circularly polarized, will the output polarization state change as we change the applied voltage? (5)

3. I wish to design an acousto optic tunable filter using $LiNbO_3$ for which $n_o = 2.27$, $n_e = 2.16$ and $v_a = 3.6$ km/s; the operating wavelength being 1 μm.
   a) What frequency of the acoustic wave would you choose?
   b) What is the required Δn and the interaction length for efficient operation with a filter bandwidth of 1 nm?
   c) For what input polarization state/states will the device work efficiently? (6)

4. The ordinary and extraordinary refractive indices of lithium niobate for 1 μm and 0.5 μm are given below:

   n_o (1.0 μm) = 2.236; n_e (1.0 μm) = 2.160
   n_o (0.5 μm) = 2.341; n_e (0.5 μm) = 2.270

a) If the ω wave is an ordinary wave and the 2ω wave is an extraordinary wave propagating along the x-direction, what period Λ_0 would you choose for QPM to generate SHG most efficiently?

b) Obtain the nonlinear polarization P_{nl} responsible for second harmonic generation. (6)

5. Starting from the following coupled wave equations and assuming no pump depletion approximation, show that difference frequency generation process can lead to amplification of the signal.

$$\frac{dE_s}{dz} = -i\,\kappa_s\, E_p\, E_i^*$$

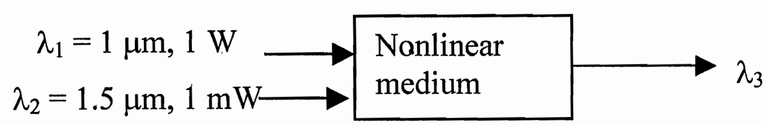
$$\frac{dE_i}{dz} = -i\,\kappa_i\, E_p\, E_s^*$$

$$\frac{dE_p}{dz} = -i\,\kappa_p\, E_s\, E_i$$

$$\kappa_i = \frac{\omega_i d}{c n_i}$$

(6)

6. Consider sum frequency generation as shown below:
   a) If $n(\lambda_\iota)$ represents the refractive index of the medium at λ_ι, what is the period for first order quasi phase matching that you would choose for maximum conversion?
   b) Obtain the maximum power at the sum frequency that can be generated.
   c) Plot schematic variations of the power at the three wavelengths as a function of propagation distance when the phase matching condition is satisfied. (5)



Some useful formulas:

$$P_+ = \frac{\sigma^2}{\sigma^2 + \frac{\Delta\beta^2}{4}} \sin^2\left(\sqrt{\sigma^2 + \frac{\Delta\beta^2}{4}}\; z\right); \qquad \sigma = \frac{\pi \Delta n}{\lambda_0}; \qquad \delta\lambda = \sqrt{3}\,\frac{\Lambda}{L}\,\lambda_0$$

For lithium niobate: $$[r] = \begin{pmatrix} 0 & -r_{22} & r_{13} \\ 0 & r_{22} & r_{13} \\ 0 & 0 & r_{33} \\ 0 & r_{51} & 0 \\ r_{51} & 0 & 0 \\ -r_{22} & 0 & 0 \end{pmatrix}; \qquad d = \begin{pmatrix} 0 & 0 & 0 & 0 & d_{15} & -d_{22} \\ -d_{22} & d_{22} & 0 & d_{15} & 0 & 0 \\ d_{31} & d_{31} & d_{33} & 0 & 0 & 0 \end{pmatrix}$$

$$\eta = K \frac{P_1}{A} L^2 \left(\frac{\sin\beta}{\beta}\right)^2; \qquad \beta = \frac{\Delta k\, L}{2}$$

h = 6.63 x 10^{-34} J.s