DEPARTMENT OF PHYSICS

Photonic Devices and Applications (PHL301) Major; May 4, 2007

Time: 2 hours
Max Marks: 40

ALL QUESTIONS ARE COMPULSORY

1. Give brief answers to the following:
   a) Consider a camera with a lens of *f*-number of 2.0 and having a focal length of 50 mm. What is the maximum distance from the camera where two point objects having a separation of 1 mm and emitting a wavelength of 500 nm will be resolved? (2)
   b) Consider a step index optical fiber with $n_2 = 1.444$, $\Delta = 0.003$ having a core radius of 4 μm. For what range of wavelengths would the fiber be single moded? (1)
   c) Consider a medium with $n_x = 1.619$, $n_y = 1.620$ and $n_z = 1.626$. A circularly polarized plane wave at a wavelength of 600 nm propagates along the *x*-axis. After how much distance would the wave become linearly polarized? (2)
   d) Linearly polarized light (polarized along *x*) at a wavelength of 500 nm propagates along the *z*-direction in a KDP crystal of length 2 cm in which an external electric field is applied along the *z*-direction. State whether the intensity at the output of the crystal will change as the applied voltage is changed. (2)
   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? (1)
   f) The refractive index of a medium at wavelengths of 1000 nm and 500 nm are given by 2.16 and 2.27 respectively. What is the velocity of the nonlinear polarization generated at the second harmonic frequency? (2)
   g) In an SHG experiment the second harmonic conversion efficiency is 2 % when the input power is 1 W. If the input wavelength is 1 μm, how many photons at the second harmonic frequency are exiting per unit time from the medium? (2)

2. I wish to achieve SHG in $LiNbO_3$ for propagation along the *y*-direction with both the waves at 1 μm and that at 0.5 μm being extraordinary polarizations; *x-y-z* refers to the principal axis system of $LiNbO_3$. The refractive indices at 1 μm and 0.5 μm are given as

   n_o (1.0 μm) = 2.24; n_e (1.0 μm) = 2.16

   n_o (0.5 μm) = 2.34; n_e (0.5 μm) = 2.26

   a) What is the period required for first order QPM?
   b) If the first order quasi phase matching is achieved by having $d(z) = d$ for $0 < z < \Lambda/2$ and $d(z) = 0$ for $\Lambda/2 < z < \Lambda$ and $d(z+\Lambda) = d(z)$, make a Fourier series expansion and calculate the effective nonlinear coefficient in the interaction process.

   (8)

3. An electric field E_z is applied along the z – axis of $LiNbO_3$.
   a) Write down the equation of the index ellipsoid in the presence of the field.
   b) For light polarized along *x* and propagating along *z*, calculate the voltage required to induce a phase shift of π on the output beams for a crystal of length L.
   c) Can one have intensity modulation for light propagation along z? Give reasons for your answer.

   (8)

4. Consider Raman Nath diffraction of a normally incident light beam of power 2 mW at $\lambda_o = 1$ μm from acoustic waves of frequency 5 MHz propagating in water (n =1.33). If the cell width is 1 cm and Δn produced by the acoustic wave is 10^{-6}, obtain the approximate power in the first order diffracted beam.

(6)

5. The coupled equations describing SHG (for phase matched case) are given by

$$\frac{dE_1}{dz} = i\kappa\, E_2 E_1^* ; \qquad \frac{dE_2}{dz} = i\kappa\, E_1^2 ; \qquad \kappa = \frac{\omega\, d}{c\, n_1}$$

Show that these equations satisfy power conservation.

(6)

Some useful formulae:

$$e^{-i\varsigma \sin\theta} = J_0(\varsigma) + 2\sum J_{2n}(\varsigma)\cos 2n\theta - 2i\sum J_{2n-1}(\varsigma)\sin(2n-1)\theta$$

$$J_n(\varsigma) \approx \frac{1}{n!}\left(\frac{\varsigma}{2}\right)^n ; \qquad \varsigma << 1$$

For lithium niobate:

$$[r] = \begin{pmatrix} 0 & -r_{22} & r_{13} \\ 0 & r_{22} & r_{13} \\ 0 & 0 & r_{33} \\ 0 & r_{51} & 0 \\ r_{51} & 0 & 0 \\ -r_{22} & 0 & 0 \end{pmatrix}$$

$r_{13} = 8\text{x}10^{-12}$ m/V, $r_{33} = 30\text{x}10^{-12}$ m/V,
$r_{51} = 28\text{x}10^{-12}$ m/V, $r_{22} = 3.4\text{x}10^{-12}$ m/V

Foe an electro optic intensity modulator: $$I_{out} = I_{in} \sin^2\left(\frac{\pi V}{2 V_\pi}\right)$$