DESIGN AND TECHNOLOGY FOR PHOTONIC INTEGRATED CIRCUIT
(ECEN 6125)

Time Allotted : 3 hrs **Full Marks : 70**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and <u>any 5 (five)</u> from Group B to E, taking <u>at least one</u> from each group.

Candidates are required to give answer in their own words as far as practicable.

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternative for the following: **10 × 1 = 10**

(i) The Lorentz oscillator model is applicable for
(a) Dielectric (b) Metals (c) Semiconductors (d) All of the above.

(ii) The Drude model
(a) is applicable for metals
(b) is a special case of Lorentz oscillator model
(c) includes mean-free-time between two successive collisions
(d) is attributed to all of the above.

(iii) The imaginary part of the complex permittivity is
(a) responsible for polarization of charges
(b) responsible for power loss
(c) responsible for determining the speed of wave in a medium
(d) none of them.

(iv) The Drude conductivity is expressed as
(a) $\sigma(\omega) = \frac{\sigma_0}{1+\frac{\omega^2}{\tau^2}}$ (b) $\sigma(\omega) = \frac{\sigma_0 \omega}{1+\frac{\omega^2}{\tau^2}}$ (c) $\sigma(\omega) = \frac{\sigma_0}{1+\omega^2\tau^2}$ (d) $\sigma(\omega) = \frac{\sigma_0 \omega}{1+\omega^2\tau^2}$.

(v) The fundamental mode of a slab waveguide having refractive index n_1 is excited by a monochromatic light. If the light incidents from a medium of propagation constant β, the wavenumber, κ, of the core is expressed as
(a) $\kappa = \sqrt{\beta^2 - k^2 n_1^2}$ (b) $\kappa = \sqrt{k^2 n_1^2 - \beta^2}$
(c) $\kappa = \sqrt{\beta^2 - \frac{k^2}{n_1^2}}$ (d) $\kappa = \sqrt{\frac{k^2}{n_1^2} - \beta^2}$

(vi) Based on the effective-index method the wavenumber of the core (refractive index n_c) of a waveguide is expressed as
(a) $\kappa = k\sqrt{n_c^2 - n_{eff}^2}$ (b) $\kappa = k\sqrt{n_{eff}^2 - n_c^2}$
(c) $\kappa = k\sqrt{n_c^2 + n_{eff}^2}$ (d) $\kappa = k\sqrt{n_{eff}^2 + n_c^2}$

(vii) For a pure dielectric materials the following model is applicable
(a) Lorentz oscillator model (b) Drude model
(c) Kramers-Kroning model (d) all of the above.

(viii) Power loss in a metal is due to
(a) real part of the complex permittivity
(b) imaginary part of the complex permittivity
(c) ordinary refractive index
(d) none of them.

(ix) The measurement of refractive index is done using
(a) a Febri-Perot interferometer (b) Mach-Zehnder interferometer
(c) Any interferometer (d) None of them

(x) According to the Bragg's condition which one is correct?
(a) $d = (n + \frac{1}{2})\frac{\lambda}{2}$ (b) $d = n\,\lambda$ (c) $d = n\frac{\lambda}{4}$ (d) $d = n\frac{\lambda}{2}$.

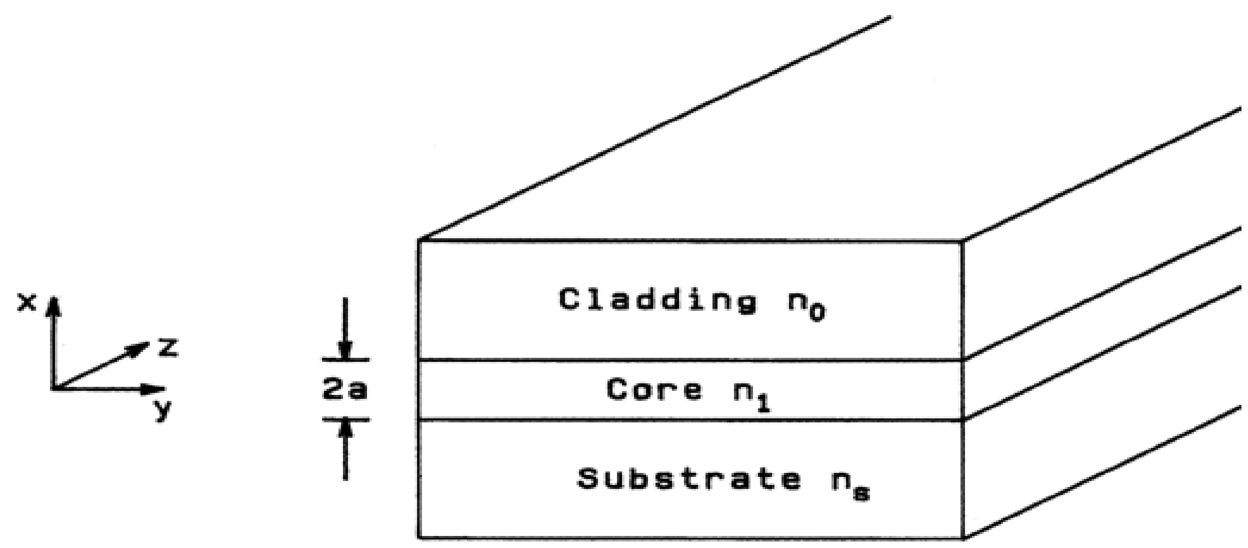
Group - B

2. (a) Recalling Lorentz-Oscillator model show that the electric susceptibility of the dielectric material can be expressed as $\chi_e(\omega) = \frac{\omega_p^2}{\omega_0^2 - \omega^2 - j\omega\,\Gamma}$, where ω_p is plasma frequency. [(CO1)(Remember/LOCQ)]
(b) Show that the imaginary and real parts of a real system are interdependent. [(CO1)(Understand/LOCQ)]
6 + 6 = 12

3. (a) Using the Kramers-Kroning relation evaluate the attenuation constant for a material of ordinary refractive index $n_0 = 2\left(\frac{\omega + a}{\omega_1}\right)$ $for\ 1 \le \omega \le \omega_1$, where a is an arbitrary constant. [(CO1)(Apply/IOCQ)]
(b) What is a uniaxial crystal? What are the main differences between an isotropic crystal and anisotropic crystal? [(CO1)(Apply/IOCQ)]
6 + 6 = 12

Group - C

4. (a) Find the electric and magnetic field of TE mode for the slab wave guide shown below. Derive and sketch for possible solutions of propagation constant. [(CO2)(Analyze/IOCQ)]



(b) Using the field equations calculated already, determine the total power carried through all the layers of the guide. [(CO2)(Analyze/IOCQ)]

6 + 6 = 12

5. (a) Design a rectangular waveguide and find the dispersion relation for E_{pq}^{x} mode of a rectangular waveguide and draw E_{12}^{x} and E_{21}^{x} modes. [(CO3)(Create/IOCQ)]

(b) Consider for a rectangular waveguide, the refractive indices of the core and cladding are 2 and 4, respectively. If $\gamma_x = 4k_x$, $\gamma_y = \frac{\pi}{6}k_y$ and dimensions along the x and y are 2 and 4 micro-meter, respectively, determine the propagation constant β for a light of wavelength $\lambda = 1.5\ \mu m$. [(CO3)(Apply/IOCQ)]

6 + 6 = 12

Group - D

6. (a) If two waveguides are placed in close proximity, how energy transfer from one guide into the other takes place. [(CO3)(Remember/LOCQ)]

(b) The coupled modes of a coupler are given as $\frac{dA}{dz} = -j\kappa B e^{-j\Delta\beta z}$ and $\frac{dB}{dz} = -j\kappa^{*} A e^{+j\Delta\beta z}$, where $\Delta\beta = \beta_1 - \beta_2$. Based on the statement judge what type of coupler it is. Find an expression of A for a coupler of length L. Assume $A(0) = A_0$ and $B(L) = 0$.

[(CO3)(Evaluate/HOCQ)]

6 + 6 = 12

7. (a) Describe the operation of Fabry-Perot interferometer? [(CO1)(Remember/IOCQ)]

(b) Design an anti reflection coating by sandwiching a material of refractive index n_2 between two other materials of refractive index n_1 and n_3. [(CO3)(Evaluate/IOCQ)]

(c) Consider two partially transmitting mirrors, separated by a homogeneous medium of width d, are placed in front of a monochromatic light source. Find an expression of the transmitted amplitude from the second mirror. [(CO1)(Analyze/IOCQ)]

4 + 4 + 4 = 12

Group - E

8. (a) Find the expression for transmission from a periodic structure that satisfies the Bragg's condition. [(CO4)(Evaluate/IOCQ)]

(b) Design a periodic structure in such a way that the reflected waves from each period will interfere constructively. What will be the relation between the wavelength and period to achieve it? Assume a monochromatic wavelength. [(CO3)(Evaluate/IOCQ)]

6 + 6 = 12

9. Explain the following phenomena for photonic crystals:

(i) Origin of photonic band-gap.

(ii) Left hand propagation.

(iii) Self collimation. [(CO4)(Remember/LOCQ)]

(4 + 4 + 4) = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	31.25	62.50	6.25

Course Outcome (CO):

After the completion of the course students will be able to

1. Students will be able to solve problems associated with wave propagation through anisotropic mediums.
2. Students will be able to design different components such as planar and rectangular waveguides, bends, Y- section, couplers, filters etc.
3. Students will be able to design coupled waveguides and resonators.
4. Students will be able to design photonic band-gap devices.
5. Students will understand the fabrication process for different optical devices.
6. Students will be able to characterize the basic photonic components using simple python coding.

*LOCQ: Lower Order Cognitive Question; IOCQ: Intermediate Order Cognitive Question; HOCQ: Higher Order Cognitive Question