DESIGN AND TECHNOLOGY FOR PHOTONIC INTEGRATED CIRCUITS (ECEN 6125)

Time Allotted : 2½ hrs **Full Marks : 60**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and any 4 (four) from Group B to E, taking one from each group.

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

Group – A

1. Answer any twelve: **12 × 1 = 12**

Choose the correct alternative for the following

(i) In free space, a wave propagating on a 2-D plane with surface normal parallel to the z axis. Which of the followings is true?
(a) Only k_x is real
(b) Both k_x and k_y are real.
(c) $k_x^2 + k_y^2 = \frac{\omega_0}{c_0}$
(d) Both (b) and (c).

(ii) In a multilayer dielectric waveguide, the propagation constant, transverse wave number and refractive index of the core are represented as $\beta, k_\perp$ and n_c. Which of the followings is true?
(a) β is conserved
(b) $\beta = \sqrt{\left(\frac{\omega_0}{c_0} n_c\right)^2 - k_\perp^2}$
(c) The cut-off wave number is $k_c = \frac{\omega_0}{c_0} n_c$
(d) All of the above.

(iii) Light, from free space, of wavelength λ_0 incidents normally on the top of a grating with grating period Λ making an angle φ with the vertical axis. If refractive index of the grating is n_{avg}, which of the followings is true?
(a) $n_{avg} \sin[\theta_m] = \sin\theta_{inc} - m \frac{\lambda_0}{\Lambda} \sin\varphi$
(b) $n_{avg} \sin[\theta_m] = - m \frac{\lambda_0}{\Lambda} \sin\varphi$
(c) $n_{avg} \cos[\theta_m] = - m \frac{\lambda_0}{\Lambda} \sin\varphi$
(d) $n_{avg} \cos[\theta_m] = \sin\theta_{inc} - m \frac{\lambda_0}{\Lambda} \sin\varphi$.

(iv) The permittivity model for metals follows
(a) Lorentz Oscillator Model
(b) Drude Model
(c) None of the above
(d) Both (b) and (c).

(v) A grating of period and refractive index 1μm and 3.5, respectively, is exposed under a light of wavelength 0.2μm. Total number of diffraction order is?
(a) 36 (b) 35 (c) 37 (d) 40

(vi) You want to design a grating to have only two diffraction order for a wavelength of 1 μm. If the grating refractive index is 3.5, what should be the period of the grating?
(a) 50.28 nm (b) 44.11 nm (c) 30.23 nm (d) 57.14 nm.

(vii) Light, from free space, of wavelength λ_0 incidents normally on the top of a grating with grating period Λ. If the grating vector $\vec{G} = \frac{2\pi}{\Lambda}$ is parallel to the incident wave vector and refractive index of the grating is n_{avg}, which of the followings is true?

(a) $n_{avg} \sin[\theta_m] = 1 - m \left|\frac{\vec{k}_0}{\vec{G}}\right|$ (b) $n_{avg} \sin[\theta_m] = 1 - \frac{m}{2} \left|\frac{\vec{G}}{\vec{k}_0}\right|$

(c) $n_{avg} \sin[\theta_m] = 1 - m \left|\frac{\vec{G}}{\vec{k}_0}\right|$ (d) $n_{avg} \cos[\theta_m] = 1 - m \left|\frac{\vec{G}}{\vec{k}_0}\right|$.

(viii) Light travelling from a homogeneous dielectric medium of refractive index n_1 being incident at an interface of another dielectric medium n_2, should have a M-matrix

(a) $\frac{1}{2n_2}\begin{vmatrix} n_1 & e^{-jnk_0 d} \\ e^{jnk_0 d} & n_2 \end{vmatrix}$ (b) $\frac{1}{2n_2}\begin{vmatrix} n_1+n_2 & n_1-n_2 \\ n_1+n_2 & n_1-n_2 \end{vmatrix}$

(c) $\frac{1}{2n_2}\begin{vmatrix} n_2+n_1 & n_2-n_1 \\ n_2-n_1 & n_2+n_1 \end{vmatrix}$ (d) $\frac{1}{2n_2}\begin{vmatrix} n_2+n_1 & n_2+n_1 \\ n_2-n_1 & n_2-n_1 \end{vmatrix}$.

(ix) A Bragg reflector works like a

(a) Fabry-Perot Etalon (b) Mach-Zehnder interferometer

(c) Both of the above (d) None of the above.

(x) If a FB etalon is compared with a resonant cavity, the finesse of the etalon can be thought as the

(a) Q of the resonator (b) Damping factor of the resonator

(c) Resonant frequency of the resonator (d) None of the above.

Fill in the blanks with the correct word

(xi) Electromagnetic modes within periodic structure are called __________ modes.

(xii) White light splits into its elementary components. This phenomenon is called ________.

(xiii) Round trip phase shift of light within a period of a distributed Bragg's reflector is__________.

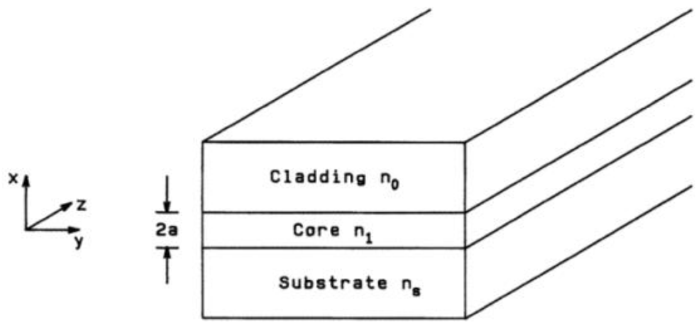
(xiv) Bending of wave front being incident on a sharp edge is called__________.

(xv) Photonic Crystals follows __________ law.

Group - B

2. (a) Derive expression of electric fields in each region of the slab waveguide shown below.

[(CO3)(Analyse/HOCQ)]



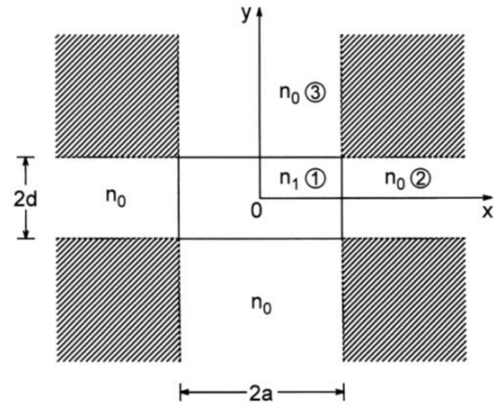
(b) If $\kappa = 0.5\sigma$ and $\sigma = \xi$, where κ, σ and ξ are the transverse wave numbers of core, cladding and substrate, respectively find the propagation constant for a slab waveguide shown above. *[(CO2)(Understand/LOCQ)]*

8 + 4 = 12

3. (a) Find magnetic fields in each region of a slab waveguide. *[(CO3)(Analyse/HOCQ)]*

(b) Ratio of transverse wave numbers between substrate to core and cladding to core are equal and given as 0.2. If the transverse propagation constant is 10×10^6 rad/m, find width of the slab waveguide to support the first order mode. Assume refractive index of the core is 2.5 and excitation wavelength is 1.2 μm. *[(CO4)(Remember/LOCQ)]*

(c) For the two dimensional optical waveguide, shown below, draw E_{12}^{y} mode profile on the xy plane. *[(CO2)(Apply/IOCQ)]*



7 + 3 + 2 = 12

Group - C

4. (a) Derive an expression of intensity for N number of waves interfering with a constant phase difference φ. *[(CO3)(Analyse/HOCQ)]*

(b) Based on the theory of interference briefly explain working principle of mach-zehnder interferometer. *[(CO4)(Remember/LOCQ)]*

6 + 6 = 12

5. (a) For a configuration shown below, show that $\beta = k_0\sqrt{\frac{\epsilon_1\epsilon_2}{\epsilon_1+\epsilon_2}}$

Where β is the propagation constant along the interface, k_0 is the free space wave number, ϵ_1 and ϵ_2 are the permittivity of dielectric and metal, respectively. *[(CO3)(Analyse/HOCQ)]*

(b) Prove that SPR modes can only be present at an interface of dielectric and metal. *[(CO4)(Remember/LOCQ)]*

8 + 4 = 12

Group - D

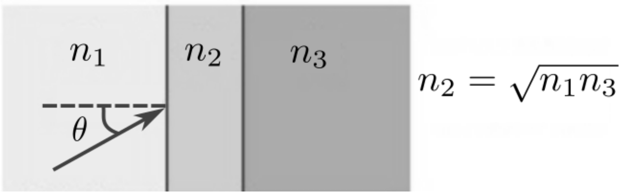
6. (a) Derive an equation for grating and explain that diffraction order increases with increasing the grating period. Support your argument using suitable diagram. *[(CO3)(Analyse/HOCQ)]*

(b) Consider a grating period 1.82μm making 45°with the vertical axis. A monochromatic light incidents from free space at an angle 45° and diffracts into the grating medium of refractive index 1.5. If the maximum grating order is 5, find the wavelength of the incident light. *[(CO4)(Remember/LOCQ)]*

6 + 6 = 12

7. (a) Prove the Bragg's Law. *[(CO3)(Analyse/HOCQ)]*

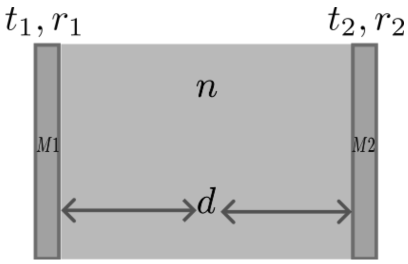
(b) Three dielectrics are forming two interfaces, as shown in the figure. Find an expression of the reflection, in terms of width of the middle layer and show that the reflection will be zero if the width $d = \frac{\lambda_0}{4n_2}$, where λ_0 is the incident wavelength. *[(CO4)(Remember/LOCQ)]*



4 + 8 = 12

Group - E

8. (a) A mirror Fabry-Perot etalon is shown in the figure below. Derive an expression of transmission intensity of the etalon and show that the finesse of the etalon is $f = \frac{\pi\sqrt{|r_1 r_2|}}{1-|r_1 r_2|}$ *[(CO3)(Analyse/HOCQ)]*



(b) A mirror Fabry-Perot etalon is to be designed with a dielectric medium of width d and refractive index 1.5, sandwiched between two identical mirrors of reflection coefficients r. If the expected FSR is 100MHz and spectral width is 0.4% of the FSR, find r and d. *[(CO4)(Remember/LOCQ)]*

6 + 6 = 12

9. (a) Derive an expression of reflection for a Bragg reflector in closed form. *[(CO3)(Analyse/HOCQ)]*

(b) Using the M-matrix theory show that total reflection from N number of reflectors can be expressed as

$R_N = \frac{\Psi_N^2 R}{1-R+\Psi_N^2 R}$, where $\Psi_N = \frac{\sin N\phi}{\sin \phi}$ and R is the reflection from each reflector.

[(CO4)(Remember/LOCQ)]

6 + 6 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	44.8	2.08	53.12

Course Outcome (CO):

After the completion of the course students will be able to
1. Select an appropriate Machine Learning tool for analyzing data in a given feature space.
2. Apply machine learning techniques such as regression, classification, clustering, and feature selection to detect patterns in the data.
3. Distinguish between supervised, and unsupervised learning.
4. Outline solution for classification and regression approaches in real-world applications.
5. Formulate a machine learning problem.
6. Determine cutting edge technologies related to machine learning applications.

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