BITS, PILANI – DUBAI
FIRST SEMESTER 2009 – 2010
COMPREHENSIVE EXAMINATION
YEAR IV ELECTIVE (EEE / EIE)

Course Code: EA C422
Course Title: Fiber Optics and Optoelectronics
Duration : 3 Hours

Date: 29.12.09
Max Marks: 80
Weightage: 40%

Instructions: (if any): Answer ALL Questions. All symbols have their usual significance. Assume appropriate values of any constant not provided

1) A step index fiber has a core refractive index n_1 and a cladding refractive index of n_2. The diameter of the core extends from y = -50 μm to y = +50 μm. The axial length of the fiber is along the x-axis. A ray of light is incident on one end of the fiber at y = 0 making an angle α with respect to the normal to the surface at y = 0. Assuming that the fiber is kept in air, the maximum allowable value of α is found to be 13°. The critical angle for the core – cladding interface is 80°.
Calculate the following:
   a) Numerical aperture of the fiber.
   b) Minimum and maximum angles of incidence that the ray of light will make at the core – cladding interface so that it can propagate through the fiber.
   c) Refractive indices, n_1 and n_2.
   d) Multipath time dispersion of the fiber.
   e) The minimum and maximum number of reflections per meter for rays guided by it along the core.

(10 marks)

2) (i) A planar rectangular waveguide is made of a core layer of index n_1 and a cladding layer of index $n_2 = 0.984n_1$. Derive an expression for the numerical aperture of the guide in terms of the incident wavelength λ, core thickness $2a$ and the maximum number of guided modes that the core can permit, M.

   (ii) A step-index planar waveguide has a core thickness of 10 μm and an incident wavelength of 1.33 μm. It is observed that by increasing the core thickness by 1.5 μm and the incident wavelength to λ_2, the maximum number of guided modes remains unchanged. Determine λ_2. If $M = 4$, determine the numerical aperture of the guide, refractive indices n_1 and n_2.

(12 marks)

3) Define the term normalized propagation constant, b and express the same as functions of the limiting values of propagations constants β_1 and β_2. With reference to a cylindrical SI fiber, determine b in terms of the normalized frequency parameter, V. Hence plot the variation of b with V for a typical guided mode, say, LP_{01}.

(6 marks)

4) Describe with appropriate chemical equations, the method of drawing optical fibers using the modified chemical vapour deposition process. What is PCVD technique? Why it is employed?

(8 marks)

PTO

BITS, PILANI – DUBAI

FIRST SEMESTER 2009 – 2010 TEST – 2 OPEN BOOK

YEAR IV ELECTIVE (EEE / EIE)

Course Code: EA C422
Course Title: Fiber Optics and Optoelectronics
Duration : 50 minutes

Date: 16.12.09
Max Marks: 40
Weightage: 20%

INSTRUCTIONS: Answer ALL questions. All symbols have their usual significance

1. A surface-emitting LED is constructed using a certain semiconductor as the active layer. A small groove on the surface from where the light emits is cemented to an optical fiber through an epoxy resin. The diameter of the fiber core is larger than that of the light emitting area of the LED. Assume negligible absorption in the semiconductor and that its refractive index is an integer value. It is found that the external quantum efficiency of the LED is 2% of its internal quantum efficiency without any epoxy resin used in the groove (that is, air). Calculate the refractive index of the semiconductor. When the groove is cemented with the epoxy of refractive index matched to that of the fiber core(n_{core} = 1.5), by how much will the external quantum efficiency of the LED increase?

(8 marks)

2. Compare the emitted power characteristics of a typical SLED with an ELED and explain why SLED can have a superior performance over ELED. What advantages would an ELED have over SLED?

(5 marks)

3. The bandgap of $Al_xGa_{1-x}As$ as a function of Al mole fraction x is shown in Figure 1. Assuming a linear variation, express $E_g(x)$ as a function of x. What composition x of $Al_xGa_{1-x}As$ would emit red light at 680 nm?

Assume h = 6.624x10^{-34}J.s, c = 3x10^{8}m/s.

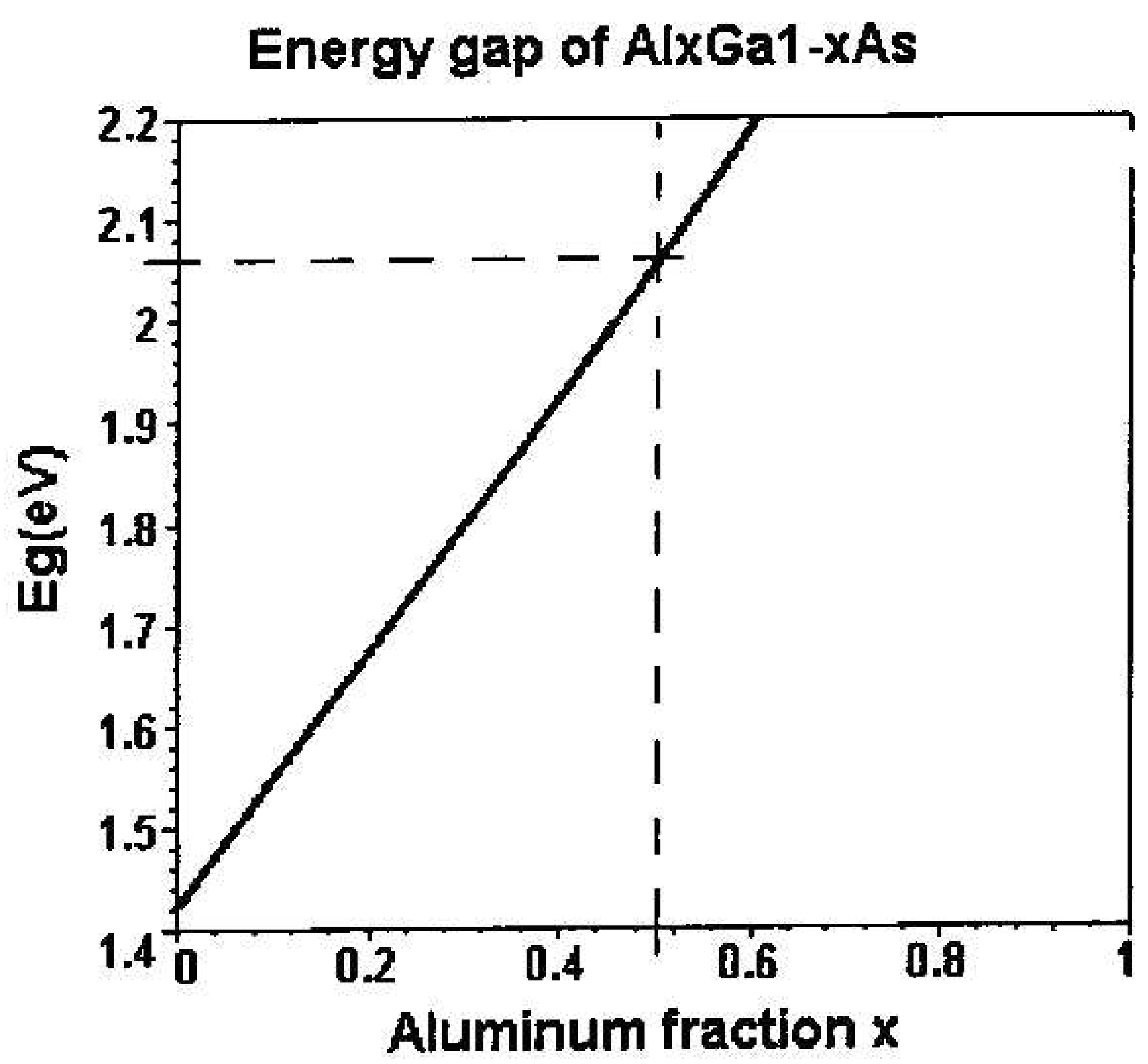


Figure 1

(6 marks)

4. A Si p-n photodiode is connected to a measuring circuit shown in Figure 2. The battery voltage is 10V. Resistance R = 5 KΩ. An incident light at wavelength 1.55 μm provides an input optical power on the photodiode of 10 μW. Under this condition, the voltmeter measures 50 mV.

(i) Determine the Responsivity R and the quantum efficiency η of the photodiode.

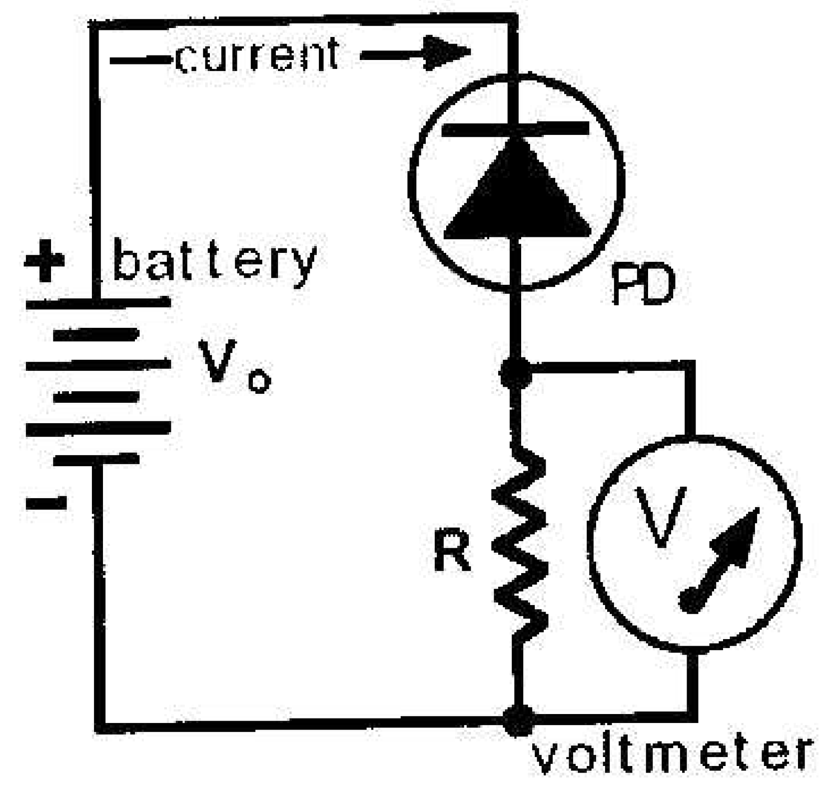


Figure 2

(ii) If the photodiode has n- and p- regions equally doped to a level of 10^{16} cm^{-3}, determine the depletion region width W where most of the incident optical power is absorbed. Assume T = 300 K, n_i = 10^{10} cm^{-3}. Dielectric constant of Si = 11.7, permittivity of free space = 8.854 x 10^{-14} F/cm, electron charge q = 1.6x10^{-19} Coulomb.

(10 marks)

5. In a longitudinal electro optic modulator, the normalized transmitted intensity is expressed as

$$\frac{I}{I_0} = \sin^2\left(\frac{\pi}{4} + \frac{\pi}{2}\frac{V}{V_\pi}\right)$$

What is the purpose of introducing the term (π/4) in the above equation? Show that the above equation reduces to $(I/I_o) = 0.5[1 + (\pi V/V_\pi)]$ when $V << V_\pi$.

(5 marks)

6. A 2x2 fiber optic coupler has a coupling coefficient of $1mm^{-1}$ for light of a certain wavelength λ. It is desired to split an incoming optical power P_o in a ratio 30 : 70. Determine the interaction length L required. Give one schematic design that gives a 4x4 coupler using only 2x2 couplers.

(6 marks)

END OF PAPER

BITS, PILANI – DUBAI
FIRST SEMESTER 2009 – 2010
TEST – 1 CLOSED BOOK
YEAR IV ELECTIVE

Course Code: EA C422
Course Title: Fiber Optics and Optoelectronics
Duration : 50 minutes

Date: 01.11.09
Max Marks: 50
Weightage: 25%

Instructions: (if any): Answer ALL Questions.

1) (i) Using the ray propagation model, explain the terms multipath time dispersion and material dispersion in a fiber. What effect would these dispersions have on the light delivered by the fiber at the output end? How can these be minimized?

(ii) Show that the pulse broadening per unit length of travel due to multipath time dispersion in a fiber can be expressed by

$$D_1 = \frac{\Delta T}{L} = \frac{n_1}{n_2}.\left(\frac{n_1 - n_2}{c}\right)$$

where n_1 and n_2 refer to refractive indices of the core and cladding layers respectively.

(iii) The speed of light in vacuum and in the core of a SI fiber is given by $3\text{x}10^8$ m/s and $2\text{x}10^8$ m/s respectively. The critical angle at the core cladding interface is 78^o. Calculate D_1.

(14 marks)

2) What are TE modes of propagation in a fiber? Sketch the field patterns for the first three TE modes in an optical fiber, showing the field distribution in the core and cladding. Hence compare the relative power loss in the cladding for the three modes.

(6 marks)

3) Differentiate between the terms phase velocity and group velocity. A cylindrical SI fiber with a core diameter of 10 μm and a core index of 1.48 has a normalized frequency parameter of 3.5 for a light of wavelength 1.55 μm. The phase velocity for the LP_{01} mode of propagation is $2.031\text{x}10^8$ m/s. Determine the normalized phase constant b for the mode.

(8 marks)

P.T.O

4) (i) Explain the terms Mode field Diameter and Fiber Birefringence in single mode fibers.

(ii) The waveguide dispersion parameter of a single mode fiber is expressed as

$$D_w = -\frac{n_2\Delta}{c\lambda}X = -\frac{n_2\Delta}{c\lambda}\left[V\frac{d^2}{dV^2}(bV)\right]$$

where the symbols have their usual significance. Calculate D_w for the fiber at $\lambda = 1.55$ μm, given that the fiber has a core index of 1.46, a relative index difference of 0.4% and a core diameter of 10 μm. Assume suitable empirical approximation for the term X.

(10 marks)

5) (i) Describe with appropriate chemical equations, the principle underlying the vapour phase deposition processes in optical fiber manufacturing. Explain with a neat sketch, the Outside Vapour phase oxidation method.

(ii) Two compatible multimode SI fibers are joined together. The refractive index of the core of each fiber is 1.5. Determine the loss efficiency due to the insertion loss at the joint when there is a small air gap.

(iii) If the two fibers also have a lateral offset of 0.25 μm and the core radius is 5 μm, determine the loss efficiency due to the lateral offset. Hence calculate the total coupling loss efficiency.

(12 marks)

End of Paper

BITS, PILANI – DUBAI
FIRST SEMESTER 2009 – 2010
QUIZ - 1

Course Code: EA C422 | YEAR IV ELECTIVE | Date: 19.10.09
Course Title: Fiber Optics and Optoelectronics | Max Marks: 32
Duration : 20 minutes | Weightage: 8%

Name: . **ID No:** .

Instructions: (if any): Answer ALL Questions. Please use both sides of the paper for your answers.

1) What are the functions of the core and cladding layers of an optical fiber? Would it be possible for light to be guided without cladding layer? Explain **[6 marks]**

2)

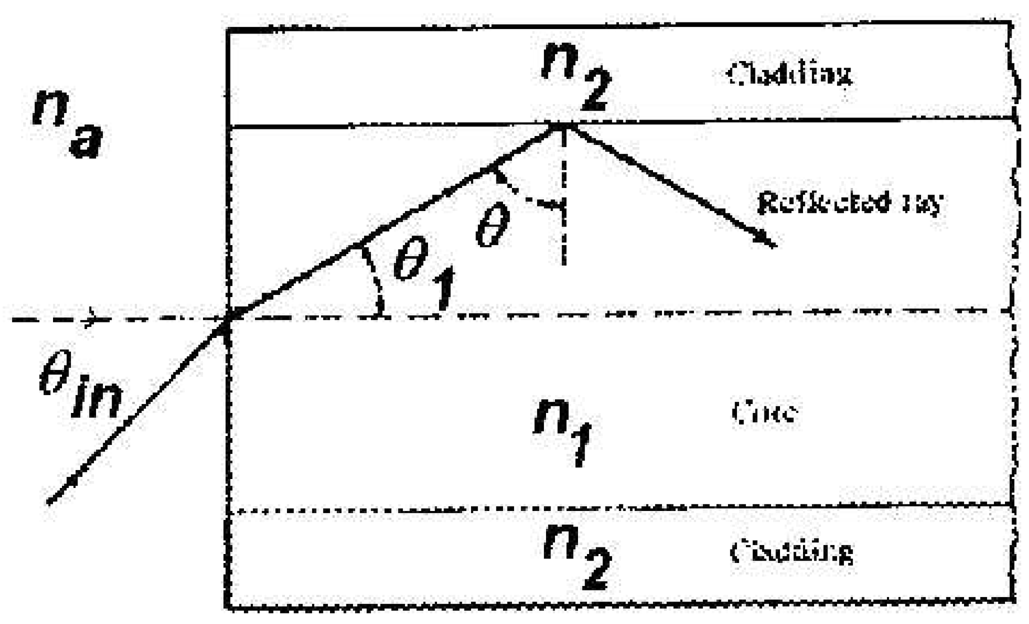


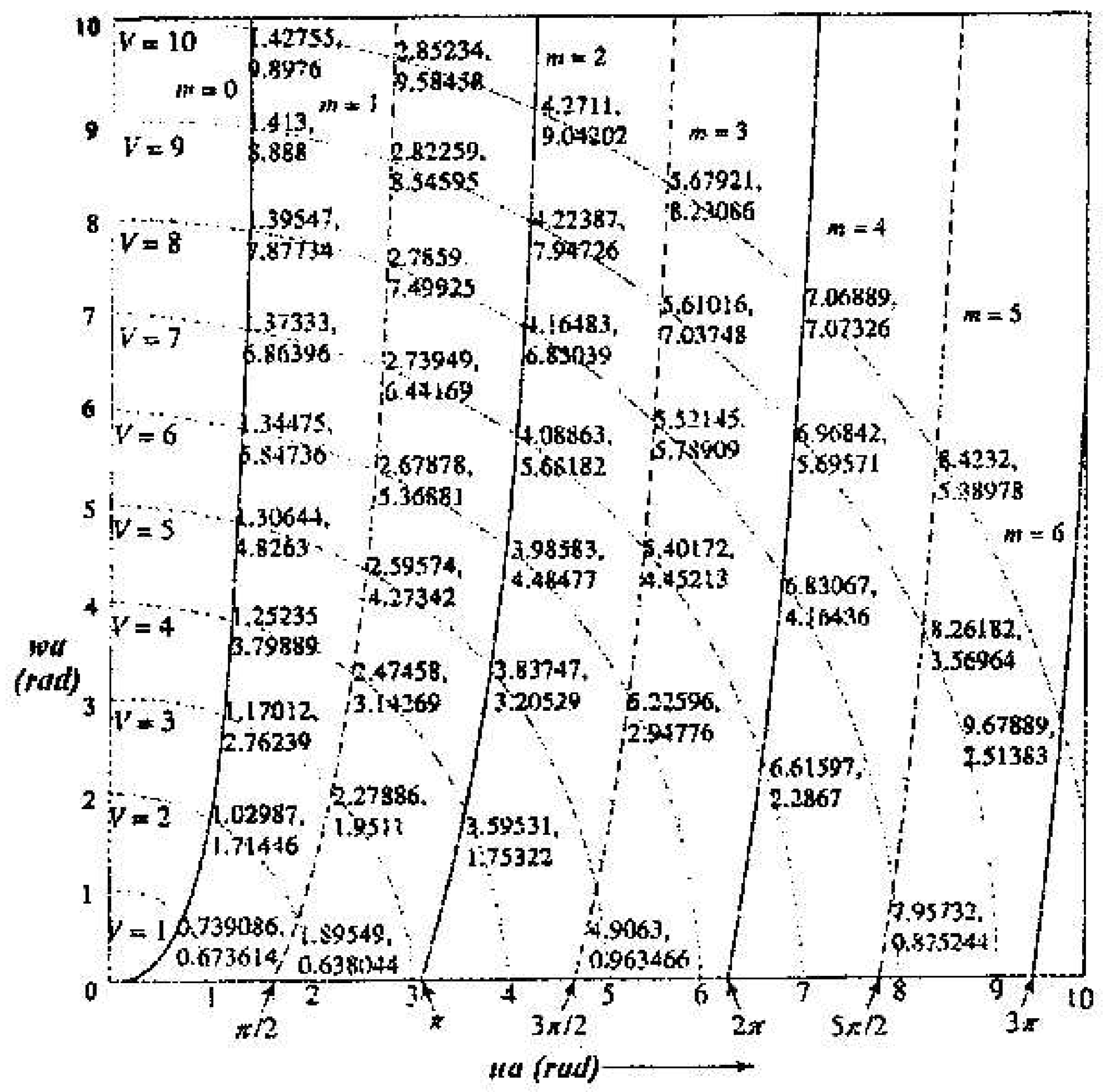
Figure 1

In a step index fiber shown in figure 1, the refractive index of the core layer is 1.5 while that of the cladding is unknown. The core diameter is 100 μm. The fiber is placed in air. The maximum value of the angle θ_{in} for light to be guided through the core is 15 °. Using the ray propagation model, determine the numerical aperture (NA) for the fiber and the refractive index n_2 of the cladding layer. Also determine the maximum possible value of the angles θ_1 and θ. **[12 marks]**

PTO

3) If the fiber as mentioned in Q2 is placed in water, would the numerical aperture increase or decrease? Explain. [4 marks]

4) Consider a symmetric step index planar waveguide formed by sandwiching a 10 μm thick core layer of refractive index 1.5 between two cladding layers of refractive index 1.48. Incident wavelength is 1.55 μm. Determine the normalized frequency parameter, V. How many TE modes can this guide support? What should be the maximum thickness of the guide layer so that it can support only the fundamental TE mode. Without changing the thickness of the guide layer, is it possible to restrict the propagation to only the fundamental mode? If so, how? **[10 marks].**



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BITS, PILANI – DUBAI
FIRST SEMESTER 2009 – 2010
QUIZ - 2

Course Code: EA C422 | **YEAR** IV ELECTIVE | Date: 07.12.09
Course Title: Fiber Optics and Optoelectronics | Max Marks: 21
Duration : 20 minutes | Weightage: 7%

Name: . **ID No:** .

Instructions: (if any): Answer ALL Questions. Please use both sides of the paper for your answers.

1) Given that m_e = .07m, m_h = 0.56m where m is the rest mass of electron, and h = 6.624 x 10^{-34} J.s, m = 9.11 x 10^{-31} kg, k = 1.38 x 10^{-23} J.K^{-1}, determine the intrinsic carrier concentration for GaAs at 300 K. The bandgap for GaAs is 1.43 eV. Why is the intrinsic carrier concentration predominant at high temperatures? [6 marks]

2) Define injection efficiency of a p-n junction diode. For a GaAs p-n diode, N_a = 5 x 10^{16} cm^{-3}, N_d = 5 x 10^{15} cm^{-3} and is at room temperature. Assume that the minority carrier diffusion lengths for electrons and holes are same and that the mobilities of electrons and holes are independent of temperature and are such that μ_e = 10 μ_h. Determine the injection efficiency. Is the efficiency affected by temperature? How should the above parameters be adjusted so as to make the efficiency maximum? [7 marks]

PTO

3) The optical modulation bandwidth of an LED is 100 MHz.. Determine the carrier lifetime τ for the LED.
[2 marks]

4) Differentiate between a p-n photo diode and a p-i-n photo diode. What is the purpose of the intrinsic layer in the p-i-n structure., A p-n photo diode requires 4 μW of input optical power to achieve a photocurrent of 3μA. If the quantum efficiency of the photodiode is 75%, determine the photon energy and the corresponding wavelength at which the diode is operating. [6 marks]

Marking Scheme

BITS, PILANI – DUBAI
FIRST SEMESTER 2009 – 2010
QUIZ - 2
YEAR IV ELECTIVE

Course Code: EA C422
Course Title: Fiber Optics and Optoelectronics
Duration : 20 minutes

Date: 06.12.09
Max Marks: 21
Weightage: 7%

Name: .	**ID No:** .

Instructions: (if any): Answer ALL Questions. Please use both sides of the paper for your answers.

1) Given that m_e = .07m, m_h = 0.56m where m is the rest mass of electron, and h = 6.624 x 10^{-34} J.s, m = 9.11 x 10^{-31} kg, k = 1.38 x 10^{-23} J.K^{-1}, determine the intrinsic carrier concentration for GaAs at 300 K. The bandgap for GaAs is 1.43 eV. Why is the intrinsic carrier concentration predominant at high temperatures? [6 marks]

$$n_i = 2\left(\frac{2\pi kT}{h^2}\right)^{3/2}(m_e m_h)^{3/4}\exp\left[-E_g/2kT\right] \quad — (2\ m)$$

$T = 300$, $k = 1.3\times10^{-23}$, $h = 6.624\times10^{-34}$,

Substitute, $n_i = 2.037\times10^{12}\ cm^{-3}$. — (2)

Explain why n_i is dominant at high temp. (2)

2) Define injection efficiency of a p-n junction diode. For a GaAs p-n diode, $N_a = 5 \times 10^{16}\ cm^{-3}$, $N_d = 5 \times 10^{15}\ cm^{-3}$ and is at room temperature. Assume that the minority carrier diffusion lengths for electrons and holes are same and that the mobilities of electrons and holes are independent of temperature and are such that $\mu_e = 10\ \mu_h$. Determine the injection efficiency. Is the efficiency affected by temperature? How should the above parameters be adjusted so as to make the efficiency maximum? [7 marks]

Defining η — 2

$$\eta = \frac{1}{1 + \left(\frac{D_h}{D_e}\frac{N_a}{N_d}\frac{\mu_e}{\mu_h}\right)} = ? \quad 3$$

Not affected by Temp — 1

Adjust. — 1

PTO

3) The optical modulation bandwidth of an LED is 100 MHz.. Determine the carrier lifetime τ for the LED. [2 marks]

$$BW = \frac{\sqrt{3}}{2\pi\tau} \quad — (1)$$

$$\tau = \frac{\sqrt{3}}{2\pi \times 100 \times 10^{+6}} = \frac{10\sqrt{3}}{2\pi} \text{ ns} \quad — (1)$$

2 (1)

4) Differentiate between a p-n photo diode and a p-i-n photo diode. What is the purpose of the intrinsic layer in the p-i-n structure., A p-n photo diode requires 4 μW of input optical power to achieve a photocurrent of 3μA. If the quantum efficiency of the photodiode is 75%, determine the photon energy and the corresponding wavelength at which the diode is operating. [6 marks]

(3)

$$R = \frac{3}{4} AW^{-1} = \frac{\eta e}{h\nu} = \frac{.75 \times 1.6 \times 10^{-19}}{h\nu}$$

$$h\nu = 1.6 \times 10^{-19} \text{ J.}$$

$$\text{Corr wavelength } \lambda = \frac{hc}{h\nu} = \frac{6.624 \times 10^{-34} \times 3 \times 10^{8}}{1.6 \cdot 10^{-19}}$$

$$= 1.24 \, \mu m.$$