BITS PILANI DUBAI CAMPUS
EA C422 – FIBER OPTICS AND OPTOELECTRONICS

II SEMESTER 2009 – 10 **COMPREHENSIVE EXAMINATION** **25 May 2010**

Total Marks : 80 Weightage: 40% Time Allowed: 3 hours

INSTRUCTIONS

1. This paper contains **ELEVEN (11)** questions and comprises **TWO (2)** pages. Answer **ALL** questions. Unless specifically stated, all symbols have their usual meanings.

Q1: Two compatible multimode step index fibers when joined with a connector, forms a lateral offset of 3 μm, an angular misalignment of core axes of 2° and 8 μm end separation with an air gap in between. If the core of each fiber has a refractive index of 1.49, a diameter of 100 μm and a relative refractive index difference of 2%, calculate the total insertion loss at the connector.

(8 marks)

Q2. A graded index optical fiber (Fiber A) with core dia 75 μm, cladding dia 125 μm and profile parameter of 2.1 is joined with another GI fiber (Fiber B) with core dia 65 μm, cladding dia 125 μm and unknown profile parameter α_2. The NA of the fibers A and B are 0.25 and 0.21 respectively. The fiber axes are perfectly aligned and there is no air gap. If the total insertion loss for transmission in the forward direction (A to B) is 5 dB, calculate the profile parameter α_2.

(6 marks)

Q3: An APD has a quantum efficiency of 60% at 1.55 μm. When illuminated with optical power of 0.5 μW at this wavelength, it produces an output photocurrent of 10 μA, after avalanche gain. Calculate the multiplication factor of the diode.

(4 marks)

Q4. Compare, with appropriate diagrams, the structure of a *p- i– n* photodiode with that of an *RAPD.* Differentiate between their electric field distribution characteristics and highlight the principal uses of these detectors.

(8 marks)

Q5. A p-n photodiode has on an average, generates five electron-hole pairs per seven incident photons for photons at a cut off wavelength of 1300 nm. Calculate the diode responsivity and the input optical power required to achieve a photocurrent of 1μA.

(4 marks)

Q6: (a) Calculate the change in the refractive index due to longitudinal electro-optic effect for a 3 mm long crystal of lithium niobate for an applied voltage of 50 V. If the wavelength of light propagating through the crystal is 550 nm, calculate the net phase shift between the two polarization components after they emerge from the crystal. For lithium niobate, $n_o = 2.29$, $n_e = 2.20$ and the relevant electro-optic coefficient, $r = 3.08\times10^{-11}$ m/V. (b) For the crystal of part (a), calculate $V\pi$.

(8 marks)

Q7. In a Pockel's longitudinal electro optic modulator, the normalized transmitted intensity is expressed as

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

What drawback would the response of this modulator have, and how such a drawback can be overcome? Hence draw a schematic of the modified Pockel's electro optic modulator and show that the transmittance response with applied voltage can be made linear, for $V << V_\pi$

(8 marks)

Q8. An impulse is launched into an optical fiber. The power, P(t), in the received pulse varies with time, t, according to the following relation:

$$P(t) = P_0 \text{ for } -\tau/2 \leq t \leq +\tau/2$$

$$= 0 \text{ otherwise.}$$

Calculate : (a) The total energy in the pulse and (b) rms pulse width. If the rms pulse width is 1 μs and P_o is 1 μW, determine the total energy in the pulse.

(8 marks)

Q9. A certain planar rectangular optical waveguide of guide thickness 2a and numerical aperture (NA) is used to propagate light at 1500 nm wavelength. It is found that the frequency parameter V increases by 1 if the wavelength is decreased to 1300 nm. The same increase in V is observed if the guide thickness is increased, with wavelength remaining unchanged at 1500 μm. By what percentage is the guide thickness increased?

(8 marks)

Q10. Given that the power confinement factor G for symmetric modes is expressed by

$$\frac{G}{wa(1-G)} = \sec^2(ua) + \frac{\tan(ua)}{ua}$$

G for antisymmetric modes can be obtained by replacing any cos(ua) term by –sin(ua) and sin(ua) by cos(ua) in the above equation.

A planar waveguide is formed from a 6.523 μm thick core film of dielectric material of refractive index 1.50 sandwiched between the cladding slabs of a similar material for which the relative refractive index difference (w.r.t. core) is 0.01324. Calculate the G factors for the modes supported by the waveguide when light of wavelength 1.0 μm is propagating through the waveguide.

(10 marks)

Q11. A fiber optic link of length 20 km has splices after every 5 km length of fiber. The link requires two connectors, one at the transmitting end and another at the receiving end. The loss at each connector is 1 dB and each splicing accounts for a 0.5 dB loss. The fiber cable has the following specifications: cable loss $\alpha_f = 0.5$ dB/km, $(\Delta T)_{intramodal} = 3$ ns/km, $(\Delta T)_{intermodal} = 1$ ns/km. The source, along with its drive circuit, has a rise time of 12 ns, while the receiver has a rise time of 11 ns. A safety margin of 5 dB is also required to be maintained, to overcome any other unforeseen losses. (a) If the minimum optical power required for a photodetector to detect at the receiving end is 20 nW, what minimum power must be supplied by the optical source at the transmitting end? (b) What is the maximum data transmission rate possible, using the NRZ code?

(8 marks)

End of Paper

BITS PILANI DUBAI CAMPUS
EA C422 – FIBER OPTICS AND OPTOELECTRONICS - Test 2

Sem2, 2009 2010
Total Marks : 40

OPEN BOOK

Time Allowed: 50 mins
Weightage: 20%

INSTRUCTIONS

1. This paper contains **SIX (6)** questions. Answer **ALL** questions. Unless specifically stated, all symbols have their usual meanings. Make appropriate assumptions wherever applicable

Q1. Why are Si based p-n junctions not suitable for use as optoelectronic sources? **(3 marks)**

Q2 The bandgap of InAs is 0.36 eV and that of GaAs is 1.43 eV. A ternary compound semiconductor $In_xGa_{1-x}As$ is formed by mixing x part of InAs with (1-x) part of GaAs where x has a value between 0 and 1. Assume that the band gap of $In_xGa_{1-x}As$ can be obtained by a linear interpolation between the limits x = 0 and x = 1. Determine the exact composition of the $In_xGa_{1-x}As$ material that would enable it to be used as an optoelectronic source emitting light at 1300 nm

(10 marks)

Q3. In selecting an optoelectronic source, the source-to-fiber coupling is often taken into account to determine the overall efficiency. An LED with an external quantum efficiency of 0.009 has an overall coupling efficiency of 0.0003 when coupled to an optical fiber. The intermediate medium between the LED and fiber is air. Determine the numerical aperture of the fiber.

(3 marks)

Q4 A certain photodiode has a responsivity R at a wavelength λ. An optoelectronic source as described in Q2 is incident on the photodiode with an optical power of 5 μW. Determine the quantum efficiency of the photodiode that is needed to provide a photocurrent of 2 μA. If due to some reason the quantum efficiency decreases by 10 %, what input optical power will be needed to maintain the same output photocurrent?

(10 marks)

Q5. Two identical single mode fibers are coupled together to form a directional coupler. It is required that an input power of 10 μW is split as 8 μW into one output port and 2 μW into the other output port. Determine at least two interaction lengths that would satisfy the above condition. The coupling coefficient is assumed as 0.5 mm^{-1}. If due to some reason the second output port delivers 1.95 μW instead of 2 μW, determine the excess loss in dB

(7 marks)

Q6. A demultiplexer is made of blazed reflection grating and operates in the range of 1500 – 1600 nm to provide a channel spacing of 15 nm. An input fiber carries all the wavelength components which are incident on a reflection grating, from where the individual components separate and exit from a lens and enter an array of output fibers. The focal length of the lens is 500 times the spacing between the core centres of adjacent output fibers. Determine the blazing angle for the reflection grating.

(7 marks)

End of Paper

BITS PILANI DUBAI CAMPUS
EA C422 – FIBER OPTICS AND OPTOELECTRONICS - Test 1

Sem2, 2009 2010 | CLOSED BOOK | Time Allowed: 50 mins
Total Marks : 50 | | Weightage: 25%

INSTRUCTIONS

1. This paper contains **FIVE (5)** questions and comprises **TWO (2)** pages. Answer **ALL** questions. Unless specifically stated, all symbols have their usual meanings.

Q1. A Corning single mode step index cylindrical fiber has the following characteristics. The fiber has been designed to provide maximum possible core diameter at a wavelength of 1.31 μm.

Corning Fiber	Fiber Type	Core Diameter (μm)	Cladding Diameter (μm)	Attenuation (dB/km)		Mode Field Diameter (MFD) (μm)	
				@1.31μm	@1.55μm	@1.31μm	@1.55μm
SMF-28e	Standard Single Mode Fiber	8.2	125	0.35	0.20		10.4

(a) Determine the numerical aperture of the fiber.

(b) If the fiber is operated at 1.55 μm wavelength, the table suggests that the mode field diameter is found to be 10.4. Based on suitable approximations, determine the expected value of the mode field diameter. Does the fiber have single mode characteristics at 0.9μm? Explain.

(10 marks)

Q2. A light pulse has a power distribution p(t) as a function of time t, as shown in Figure 1. The FWHM of the pulse is τ.

(a) Write down the expressions for p(t) in the range $-\Delta T/2 < t \leq 0$ and $0 < t \leq \Delta T/2$.

(b) Show that the energy associated with the pulse is $p_o.\tau$.

(c) Determine the rms pulse width σ

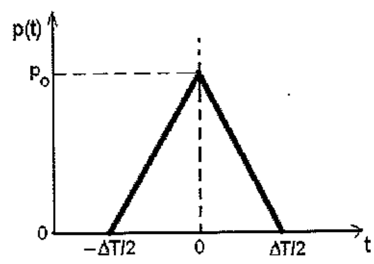

Figure 1

(10 marks)

Q3 A certain planar rectangular optical waveguide of guide thickness 2a and numerical aperture (NA) is used to propagate light at 1.33 μm wavelength. It is found that the frequency parameter V decreases by 1 if the wavelength is increased to 1.55 μm. The same decrease in V is observed if the guide thickness is decreased, with wavelength remaining unchanged at 1.33 μm. By what percentage is the guide thickness decreased?

(10 marks)

Q4. Design a planar rectangular optical waveguide so as to have a maximum guide thickness to allow two modes of propagation at wavelength $\lambda = 1.55\ \mu m$. The critical angle for the guide – cladding interface is 80^o. The guide refractive index is 1.5. Which of the two modes will have maximum power confined within the guide? Why? If the wavelength is reduced to $0.9\ \mu m$, how many modes can the guide support now? Under what condition is the power confinement factor for any mode high?

Given that the power confinement factor G for symmetric modes is expressed by

$$\frac{G}{wa(1-G)} = \sec^2(ua) + \frac{\tan(ua)}{ua}$$

G for antisymmetric modes can be obtained by replacing any cos(ua) term by –sin(ua) and sin(ua) by cos(ua) in the above equation

(10 marks)

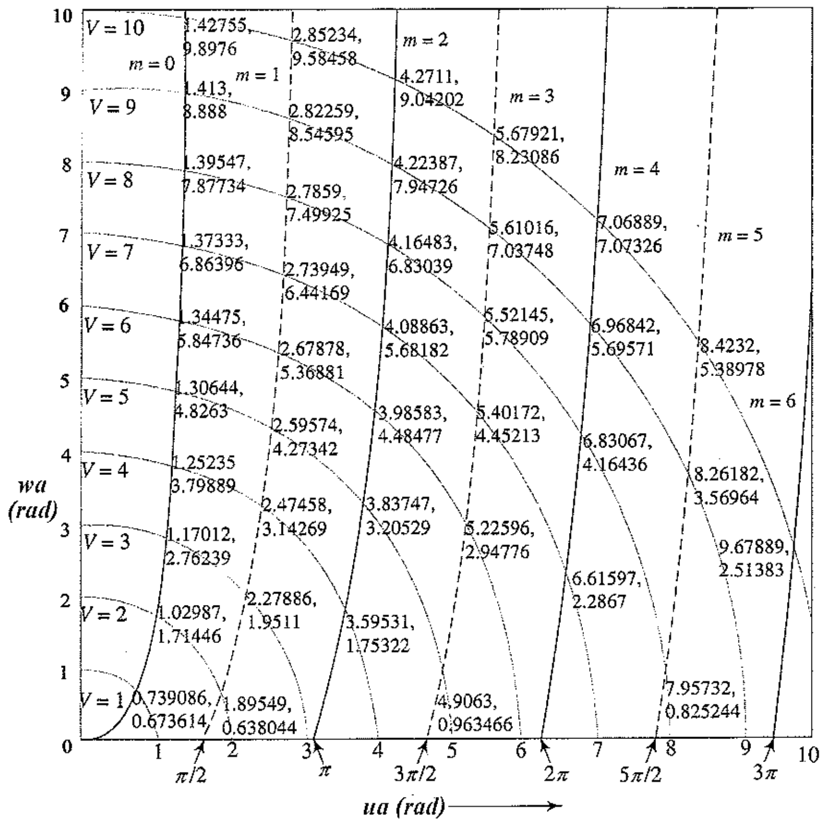

Figure 2

Q5 Differentiate between material dispersion and waveguide dispersion. A step index single mode cylindrical fiber exhibits material dispersion of 3 ps $nm^{-1}km^{-1}$ at $1.33\ \mu m$ wavelength. Calculate the diameter of the core needed to make the total dispersion zero at this wavelength. Assume $n_1 = 1.5$, $n_2 = 1.49$.
If the wavelength is increased to $1.55\ \mu m$, will the total dispersion increase or decrease? What methods can be adopted to make the total dispersion zero at this wavelength?

(10 marks)

End of Paper

NAME: ID NO.: SET B

BITS PILANI DUBAI CAMPUS

EA C422 – FIBER OPTICS AND OPTOELECTRONICS - Quiz 2

Sem2, 2009 2010 CLOSED BOOK Time Allowed: 20 mins

Total Marks : 28 Weightage: 7%

INSTRUCTIONS

1. This paper contains **FOUR (4)** questions and comprises **TWO (2)** pages. Answer **ALL** questions. Unless specifically stated, all symbols have their usual meanings.

Q1 A p-n photodiode is used as an optical detector. What factors are needed to be considered in order to improve the response of the detector to any incident radiation? What are the limitations of the p-n detector and how they are overcome in a p-i-n diode?

A p-n diode generates two electron-hole pairs out of every 3 incident photons corresponding to a wavelength of 0.9 μm. The response of a photodiode is in the form of a photocurrent I_p for an incident optical power P_{in}. Responsivity of the diode is defined as $R = I_p/P_{in} = (ne)/E_p$, where n is the quantum efficiency of the diode, e is the electronic charge and E_p is the photon energy. For an input optical power of 10 μW, what is the generated photocurrent?

[8 marks]

Q2 Draw the band diagram of a light emitting diode which is biased in a manner that it is able to emit radiation. Mark the conduction bands, valence bands, Fermi levels and the depletion region edges in the diagram. [4 marks]

Q3. Two identical fibers having a core diameter of 0.5 μm and a numerical aperture of 0.22 are spliced almost perfectly, except for a small air gap of thickness 0.04μm that is formed at the joint. When tested, there was an overall loss of 0.5 dB at the joint. Determine the refractive indices of the core and cladding layers. [8 marks]

Q4. State the basic requirements to be met for any material that can be used for the fabrication of an optical fiber. Apart from glass what other material can be used for short distance transmission applications? Describe the modified CVD method of production of fibers. How can one increase the deposition rate? [8 marks]

The End

SET A

BITS PILANI DUBAI CAMPUS
EA C422 – FIBER OPTICS AND OPTOELECTRONICS - Quiz 1

Sem2, 2009 2010 | CLOSED BOOK | Time Allowed: 20 mins
Total Marks : 16 | Weightage: 8%

INSTRUCTIONS

1. This paper contains **FIVE** (5) questions and comprises **TWO** (2) pages. Answer **ALL** questions. Unless specifically stated, all symbols have their usual meanings.

Q1 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, L is the length of fiber. **[4 marks]**

Q2

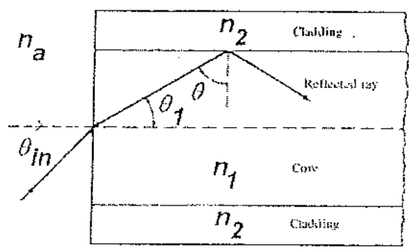

Figure 1

In a step index fiber shown in figure 1, the maximum value of the angle θ_{in} for light to be guided through the core is 14.1°. The fiber is placed in air. The critical angle at the core cladding interface is 80.6°. Determine the refractive indices n_1, n_2 of the core and cladding layers. If the fiber is placed in water, what will be the maximum angle θ_{in} ?. **[6 marks]**

Q3. For a symmetrical step index planar waveguide, core index $n_1 = 1.5$, and $\Delta = 0.001$. If the thickness of the guide is 10 μm, for what wavelength will the guide support only the fundamental; mode? Explain. [2 marks].

Q4. The maximum number of TE modes supported by a symmetrical step index planar waveguide is the nearest integer greater than

(a) $2V/\pi$ (b) $3V/\pi$ (c) $3V/2\pi$ (d) V (e) zero (f) none of above

(V is the frequency parameter) [1 mark]

Q5. Draw the electric field distribution for the first three TE modes (m = 0, 1 and 2) of a planar waveguide. Show the distribution in both core and cladding layers. [3 marks]

The End