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Currently no one reported. 2.1 symmetrical guide of the wave of the dielectric plate Consider two rays like 1 and 2 interfering to point P in Figure 2.4 Both move with the same angle of incidence but have several m wavectors just before point P. In addition, there is a difference of phase between the two due to the different paths taken to reach point P. We can represent the two waves like E1(y,z,t) = Eocos(tmy) it has been used to indicate that the waves have a phase difference and travel different optical paths to reach point P. We also know that m = k1cosm and m = k1sinm, and of course they have the condition of the already incorporated waveguide inthrough m. Show that the overlap of E1 and E2 to P is given by E(y, z,t) 2Eo cos(m y 2)cos(t m z 2)1 1 What to doAre the terms of things? The planar waveguide is symmetric, which means that the intensity, E2 , must be maximum (also m) or minimum (odd m) at the center of the guide. Choose the appropriate values and trace the relative magnitude of the electric field through the guide for m = 0, 1 and 2 for the following dielectric symmetric guide: 1 = 1.4550, n2 = 1.4400, a = 10 m, = 1.5 m (free space), the first three modes have 1 = 88.84, 2 = 87.673 = 86.51. Scale the field values so that the maximum field is the unit per m = 0 at the center of the guide. (Note: Alternatively, it is possible to choose in order that the intensity (E2) is equal to the boundaries to y = a and y = a; it would give the same distribution.) Solution E(y) Eo cos(t m z z) Eo cos(t m z m z) Use the appropriate trigonometric identity (see Appendix D) for cosA + cosB to express it as a product of 2cos cosines[(A+B)/2]cos[(AB)/2], E(y, z,t) 2Eo cos(m y di propagate long)cos(t m z 2 Thus, the amplitude is amplitude = 2Eo cos(m y 2) The intensity is maximum or minimal in the center. We can choose = 0 (m = 0), = (m = 1), = 2 (m = 2), which would result in maximum or minimum intensity in the center. (In fact, = m). Field distributions are shown in Figure 2Q1-1. 3. Manual Solutions (Preliminary) 11 December 2012 Chapter 2 2.3 Figure 2Q1-1 Amplitude of the electric field through the dielectric planar waveguide. Red, m = 0; blue, m = 1; black, m = 2. 2.2 Waves standing inside the core of a symmetrical dielectric wave guide. Permitted upwards and down travel waves within the core of the planar wave guide sets-up a stationary wave along you. The wave standing can only exist if the wave can be replicated after it traveled along the y direction on a round trip. Put differently, a wave thata A in Figure 2.51 and travelthe upper face travels along you, it is reflected in B, travels down, reflects again in A, and then would travel in the same direction as it started. At this point, it must have a phase identical to its initial phase so that it can replicate and not destroy itself. Since the long wave vector y is m, it derives the condition of the wave guide. Figure 2.51 Waves of travel upwards and downwards along sets a wave standing. The condition for setting a standing wave is that the wave must be identical, able to replicate, after a long lap y. Solution From Figure 2.51 you can see that the optical path is AB BA 4a With the radius in phase change with each reflection the total phase change is 4am 2 4. Manual Solutions (Preliminaries) 11 December 2012 Chapter 2 2.4 The wave replicates, it is the same phase after the only return, so 4am 2 2m and m k1 cosm . 2n1 ' cosm we get 2n1(2a) cos. m as required. m 2.3 Waveguide of the dielectric plate (a) Consider the two parallel rays 1 and 2 in Figure 2.52. Show that when you meet at C at a distance y above the driving center, the phase difference is m = k12(a y)cosmm (b) Using the waveguide condition, show that y m (y) m ' (m m) to (c) The two waves that interfere with C can be more simply and comfortably represented as E(y) Acos(t m (y) Then find the amplitude of the field variation along you, through the guide. What's your conclusion? Figure 2.52 Rays 1 and 2 are initially in phase as they belong to the same wave. Ray 1 experiences total internal reflection at A. 1 and 2 interfere with C. There is a difference in phase between the two waves. Solution (a) From geometry we have the following: (a y)/AC = cos e and C/AC = cos(2) The phase difference between the waves that meet at C is = kAC kAC = k1AC k1AC k1ACcos(2) 5. Solution Manual (Preliminary) 11 December 2012 Chapter 2 2.5 m di y di 2 2 di di di]] = = (a) m Thus, E 2Acos[t 1 m (y)]cos1 m (y) or E 2Acos1 m (y)cos(t) = Eocos(t +) in which m/2, and t +) is the dependent part of the time that represents the wave phenomenon, and curly brackets contain the effective amplitude. So, the Eo width is E 2Acos m' y (m)o 2a m To plot Eo as y function, we need to find m by m = 0, 1 , 2... The variation of the field is a truncated cosine function) with its maximum at the center of the guide. See Figure 2Q1-1. 2.4 TE field model in waveguide of the slab Consider two parallel beams 1 and 2 which interfere in the guide as in figure 2.52. Given the difference in phase (y) m y (m)m m a m between the waves to C, distance y above the driving center, find the model of electric field E (y) in the guide. We remember that the field at C can be written as E(y) Acos(t) Acos[t m (y)]. It sets the field model for the first three modes that take a planar dielectric guide with a core thickness 20 m, n1 = 1.455 n2 = 1.440, light wavelength of 1.3 m. 6. Solution Manual (Preliminary) 11 December 2012 Chapter 2 2.6 ' 2 n 1 m ' Figure 2.52 Rays 1 and 2 are initially in phase to belong to the same wave front. Ray 1 experiences total internal reflection at A. 1 and 2 interfere with C. There is a difference in phase between the two Solution The two waves that interfere with C are out of phase from, E(y) Acos(t) Acos[t m (y)] where A is an arbitrary amplitude. So, E 2Acos , t 1) (y) cos 1) (y) 2 m 2 m 1 o or E 2Acos 2 m (y)cost = Eocos(t +) , in which m/2, and cos(t) +) is the part dependent on the time that represents the wave phenomenon, and thethe ricci contain thewidth. Thus, the Eo width is E 2Acos m' y (m)o 2a m To plot Eo as y function, we must find m by m = 0, 1 and 2 , the first three modes. From example 2.1.1 in the textbook, the waveguide condition is (2a)k1 cosm m we can now replace m which has different shapes for TE and TM waves to find, per1/ 2 sin2 , n2 m onde 1 waves of TE abound because m perché 2 qua qua qua qua qua qua qua qua qua qua qua qua esempio Alternatively you can use a computer program to find the roots of a function. The above equations are m only for each m. Use of a = 10 m, = 1.3 m, n1 = 1.455 n2 = 1.440, The results are: TE mode m = 0 m = 1 m = 2 m (grades) 88.84 , m (grades) 163.75 147.02 129.69 di TM Mode m = 1 m = 2 m (grades) 88.66 There is no significant difference between TE and TM modes (the reason is that n1 and n2 are very close). Figure 2Q4-1 Field distribution through the core of a planar dielectric waveguide We can set A = 1 and track Eo vs. y using E 2cos m. y (m)o 2a m with the m and m values in the above table. This is shown in Figure 2Q4-1. 8. Solution Manual (Preliminary) 11 December 2012 Chapter 2 2.8 2 2 2 2 n 1 m 2 n 1 m 2 di 2.5 2.5 TE and TM Dielectric waveguide mode of the slab Consider a planar dielectric guide with a core thickness 20 m, n1 = 1.455 n2 = 1.440, light wavelength of 1.30 m. Given the waveguide condition, and expressions for phase and TIR changes for TE and TM modes respectively, rispettivamente 1/ 2 rispettivamente n 1/ 2 sin 2 di n2 rispettivamente 2 m n rispettivamente 2 m n rispettivamente m n1 1 tan1 and 2 m cos e 2 n '2 ' n cosm 1 ' using a graphical solution find the cornerthe fundamental constant propagation and comparison modesguide. Solution The waveguide condition is (2a)k1 cosm m we can now replace m which has different shapes for TE and TM waves to find, ,1/2 sin2 n2 m 1 1 TE waves to tan because m perché 2 ogni , cosm ' 1/ 2esempio fTE (m) sin2 esempio n2 m esempio 1 TM waves to tan m esempio 2 Alternatively you can use a computer program to find the roots of a function. The above equations are functions of m only for each m. Using a = 10 m, = 1.3 m, n1 = 1.455 n2 = 1.440, the results are: TE m = 0 m (grades) 88.8361 m = k1sinm 7,030,883 m-1 odalità TM Mode m = 0 m (grades) 88.8340. m= k1sinm 7,030,878m-1 odalità Note that 5.24 m-1 and -difference is only 7.510-5 %. The following intuitive calculation shows how the small difference between TE and TM waves can lead to dispersion which is the time diffused in the arrival time of the TE and TM optical signals. 9. Solution Manual (Preliminaries) December 11, 2012 Chapter 2 2.9 m Suppose it is the delay time between TE and TM waves on a length L. Then, 1 Poi (5.24 m1)TE TM L vTE vTM di (1.45 1015 rad/s) = 3.610-15 s m-1 = 0.0036 ps m-1 . Over 1 km, TE-TM wave scatter is ~ You should warn that we calculated the dispersion using the phase speed while we should have used the group speed. 2.6 Group speed We can calculate the group speed of a certain mode as a frequency function using a convenient mathematical software package. It is assumed that the mathematical software package can perform symbolic algebras such as partial differentiation (the used author Livemath, , although others may be used). The propagation constant of a given mode is = k1sin where and implies m and m. The objective is to express and in terms of . From k1 = n1/c, the condition of the guideis sin2 (n/n)2 1/ 2 tana il sin cos cos m il 2 perché 2 1 because the tan arc sin2 sin2/ n)2 m(/ 2) F () (1) to 2 1 m where Fm() and a function of a given m. The frequency is given by c c f () (2) n1 sin. n1 sin Both and are now a function of Eqs (1) and (2). Then the speed of the group is differentiating Eqs (1) and (2) from d d d d d d c Fm() cos a ( ) a 1 v g d a d n sin F a sin2 m F () 1 ' m c differenzia Fm () i.e. vg 1 cot a n sin F () di Group speed, planar wave guide (3) 1 m termine For a given m value, Eqs (2) and (3) can be traced parametrically, that is, for each value we can calculate and vg and vg vsg plot. Figure 2.11 shows an example for a guide with the characteristics of the figure caption. Using a convenient mathematical software package, or by other means, get the same vg vs. behavior, discuss intermodal dispersion, and if the Equation (2.2.2) is appropriate. 10. Manual Solutions (Preliminaries) December 11, 2012 Chapter 2 2 2.10 Solution The results displayed in Figure 2.11 and Figure 2Q6-1 were generated by the author using LiveMath based on Eqs (1) and (3). Of course, other mathematical software packages can also be used. The important conclusion of Figure 2.11 is that although the maximum speed of the group is c/n2, the minimum speed of the group is not c/n1 and can be lower. The equation (2.2.2) in §2.2 is based on the use of vgmax = c/n2 and vgmin = c/n1, i.e. taking the speed of the group as a phase speed. So, it's just approximate. Figure 2Q6-1 Group speed vs. angular frequency for three modes, TE0 (red), TE1 (blue) and TE4 (orange) in a planar dielectric waveguide. The horizontal black lines mark the phase velocity in the core (lower line, c/n1) and in the coating (top line, c/n1). 2.7 Dielectric Layer Wave Guide Consider a waveguide of the dielectric plate that has a thin layer of GaAsthickness 0.2 m between two layers of algaas. the refractive index of gaas is 3.66 and that of the layers of algaas is 3.40. what is cuttingbeyond which only a single mode can propagate in the waveguide, assuming that the refractive index does not vary considerably with the wavelength? if a 11. manual solutions (preliminaries) 11 December 2012 Chapter 2 2.11 radiation of wavelength 870 nm (corresponding to bandgap radiation) propagates in the gaas layer, what is the penetration of the evanescent wave in the algaas layers? What is the width of the mode field (mfw) of this radiation? 1/0.0.2 (b) 0,0.1 depth of penetration is half the thickness of the nucleus. the width between two and-1 points on the field decay into the coating is width = 2a + 2× = 0.2 m + 2(0.102) m = 0.404 m. 2.8 waveguide of the dielectric plate consider a dielectric waveguide to the plate that has a core thickness (2a) of 20 m, n1 = 3.00, n2 = 1.50. the solution of the waveguide condition in eq. (2.1.9) (e.g. 2.1.1) gives mode angles 0 and 1 for te0 and te1 modes for selected wavelengths as summarized in table 2.7. for each wavelength calculate and m and then the plot vs. - Yeah. on the same plot show the lines with slopes c/n1 and c/n2. compare your plot with the scatter diagram in figure 2.10 12. manual solutions (preliminaries) 11 December 2012 chapter 2.12 table 2.7 the solution of the waveguide condition for a = 10 m, n1 = 3.00, n2 = 1.50 gives the angles of incidence 0 and 1 for modes 0 and 1wavelengths indicated. 15 20 25 45 4570 100 150 200 0' 77.8 74.52 71.5 68.7 63.9 61.7 59.74 53.2 46.4 39.9 36.45 1' 65.2 58.15 51.6 45.5 35.5 32.02 30.17 - - - Solution Consider the example of the case for = 25 m = 25×10-6 m. The propagation constant of the free space k = 2/ = 225×10-6 m = 2.513×105 m-1 . The propagation constant within the nucleus is k1 = n1k = (3.00)(2.513×105 m-1) = 7.540×105 m-1 . The angular frequency = ck = (3×108 m s-1)(2.513×105 m-1) = 7.54 Which is listed in table 2Q8-1 in the second row below = 25 m. The propagation constant along the guide, long z is given by Eq. (2.1.4) so that m = k1sinm or 0 = k1sin0 = (7.540×105 m-1)sin(71.5) = 7.540×105 m-1 = 7,15×105 m-1. which is the value indicated in the 2Q8-1 bold table for m = 0 = 25 m. Now we have both 0 and 1 to = 2.54×1013 s-1. We can track this 1 point for the mode m =0 to 0 = 7,15×105 m-1 along the x axis, taken as the axis - and = 2,54×1013 s-1 along the y axis, taken as the axis -, as shown in Figure 2Q8-1. We can also track the 1 point we have for the m = 1. mode The propagation constants () at other wavelengths and therefore the frequencies () can be calculated in the same way. The results are listed in Table 2Q8-1 and traced in Figure 2Q8-1. This is the dispersion diagram. For comparison the scatter vs for the core and coating are also shown. They are designed so that the slope is c/n1 for the core and c/n2 for the coating. 5. 5. 5. 5. 5. 5. 5. 5. 5. 5. 5. 5# - 13. Manual Solutions (Preliminary) 11 December 2012 Chapter 2 2.13 0 105 1/m 12.3 9.08 7.15 5.85 4.23 3.69 3.26 2.16 1.37 0.81 0.56 1 105 1/m 11.4 8.01 5.91 4.48 2.74 2.22 1.89 - - - Figure 2Q8-1 Dispersion diagram for a planar waveguide Black, TE0 mode. Viola: TE1 mode. Blue: Propagation along the coating. Red: Propagation along the nucleus. Author's Note: Remember that the slope at a particular frequency is the speed of the group at that frequency. As evident, for the TE0 mode (m = 0), this slope is initially (many long wavelengths) along the blue curve at low frequencies, but then along the red curve at high frequencies (many short wavelengths). The speed of the group changes from c/n2 to c/n1. 2.9 Dielectric waveguide Dielectric plate waveguide Consider a dielectric planar waveguide with a core thickness 10 m, n1 = 1.4446, n2 = 1.4440. Calculate the number V, the angle of mode m = 0 (use a graphic solution, if necessary), the depth of penetration and the width of the field of mode, MFW = 2a + 2, for light wavelengths of 1.0 m and 1.5 m. What's your conclusion? Compare your MFW calculation with 2wo = 2a(V+1)/V. The mode angle 0, is given as 0 = 88.85 per = 1 m and 0 = 88.72 per = 1.5 m for the basic mode m = 0. Solution = 1 m, n1 = 1.4446, n2 = 1.4440, a = 5 m. Manual Solutions (Preliminaries) 11 December 2012 Chapter 2 2.14 2 n 1 m ' m Solve the condition of waveguide condizione 1/ 2 sin2 ' n2 m ' 1 tanak cos m ' 2 condizione cosm f (m) graphically as in example 2.1.1 to find: c = 88.35 and the mode angle (per m = 0) is or = 88.85. Then use n 2 1/ 2 2n2 1 di sin2 di 1 1 m n2 to calculate penetration depth: = 1/= 5.33 m. MFW = 2a + 2 = 20.65 m We can also calculate MFW from MFW = 2a(V+1)/V = 2(5 m) (1.3079+1)/(1.3079) = 17.6 m (D72)the condition of the waveguide graphically that the mode angle= 88.72. = 1/= 9.08 m. MFW = 2a + 2 = 28.15 m. Compare with MFW = 2a(V+1)/V = 2(5 m)(0.872+1)/(0.872) = 21.5 m (Difference = 24%) Note that the MFW from 2a(V+1)/V worsens as V decreases. The reason for using MFW = 2a(V+1)/V is that this equation provides a calculation at a single step of MFW. The calculation of the depth of penetration requires the calculation of the angle of incidence and . Consider a more extreme case = 5 m, V = 0.262, single mode. Solve the waveguide condition graphically to find out that the way angle is or = 88.40. = 1/= 77.22 m. MFW = 2a + 2 = 164.4 m. Compare with MFW = 2a(V+1)/V = 2(5 m)(0.262 + 1)/(0.262) = 48.2 m (Very big difference). 2.10 A multimodal fiber Consider a multimodal fiber with a core diameter of 100 m, core refraction index of 1.4750, and a coating refraction index of 1.4550 and 850 nm. Consider the operation of this fiber to = 850 nm. (a) Calculate the number V for the fiber and estimate the number of modes. (b) Calculation 15. Manual Solutions (Preliminary) 11 December 2012 Chapter 2 2.15 2 the wavelength beyond which the fiber becomes single mode. (c) Calculate the numerical opening. d) Calculate the maximum acceptance angle. (e) Calculate the modal dispersion and then the remote bit rate product. Data n1 = 1.475, n2 = 1.455, 2a = 10010-6 m or = 50 m and = 0.850 m The V-number is, 2 2 2 1/2 V 2a n2 1/ 2 2 2 2π(50 μm) (1.475 1.455) = 89.471 2 M mode number (0.850 μm) M V di 2 89.472 2 4002 The fiber becomes monomode when, V 2a n2 1/ 2 2.4051 2 2an2 n2 1/ 2 2(50 μm)(1.4752 1.4552)1/ 2 or o 1 2 . 2.405 2.405 = 31.6 m For wavelengths greater than 31.6 m, the fiber is a waveguide in single mode. The NA numerical aperture is 2 2 1/ 2 2 1/ 2 NA (n1 n2) (1.475 1.455) = 0.242 If max is the maximum acceptance angle, then, NA max arcsin' no modular dispersion is given by arcin(0.242 /1) = 14 inter intermode n1 n21.455 l c 3108 m s-1 = 66.7 ps m-1 or 67.6 ns per km as 0.29, maximumis BL 0.25L 0.25L 0.25L 0.25 Total intermode (0.29)(66.7 ns km-1) i.e. BL = 13 Mb s-1 km (only one estimate) We neglected material dispersion at this wavelength which would further decrease BL. Material dispersion and modal dispersion must be combined with 2 2 2 2 total intermodal material 16. Manual Solutions (Preliminaries) 11 December 2012 Chapter 2 2.16 For example, assuming a LED with a spectral deviation of about 20 nm, and a Dm 200 ps km-1 nm-1 (about 850 nm) we will find material dispersion as material = (200 ps km-1 nm-1)(20 nmdale)(1 km) 4000 ps km-1 or 4 ns km-1 , which is substantially smaller 2.11 A water jet guiding light One of the first demonstrations of how light can be driven along a high means of refraction through total internal reflection involved that illuminates the starting point of a jet of water as it comes out from a water tank. The water refraction index is 1.330. Consider a water jet of 3 mm diameter which is illuminated by green light of 560 nm wavelength. What is the number V, the numerical opening, the total acceptance angle of the jet? How many ways are there? What is the cut wavelength? The diameter of the jet increases (low) as the jet flows away from the original sprout. However, the light is still guided. Why? Guided light along a thin water jet. A small hole is made in a bottle of water-filled plastic soda to generate a thin water jet. When the hole is illuminated with a laser beam (from a green laser pointer), the light is guided by total internal reflections along the jet to the tray. Water with air bubbles (produced by bottle agitation) was used to increase light visibility. Air bubbles disperse the light and make the light visible. Firstly, this demonstration was attributed toDaniel Colladon, a Swiss scientist, who demonstrated a water jet driving light in 1841. V-number solution 2 1/2 - 3 -9 2 2 1/2 V = (2a/)(n1 2 n2) Numerical opening = =550×10)(1.330 1.000) = 15104 NA= (n1 2 n2 2)1/2 = (1.3302 1.0002)1/2 = 0.8814 Total acceptance angle, assuming that laser light is launched within the sinmax water medium = NA/n0 = 0.113/1.33 or max = 41.4°. Total acceptance 2o = 82.8odalità Mode = M = V2 /2 = (15104)2 /2 = 1.14×108 mode (~100 thousand mode) The wavelength of the curoff corresponds to V = 2.405, i.e. V = (2a/)NA = 2.405 c = [2aNA]/2.405 = [(2)(4 m)(0.8814)]/2.405 = 3.5 mm The big difference of refractive indices between water and air ensures that total internal reflection occurs even when the flow width increases, which changes the angle of incidence. 2.12 Single-mode fibre Consider a fiber with a 86.5%SiO2-13.5%GeO2 8 m diameter core and refractive index of 1.468 and a coating refractive index of 1.464 refractive indices at 1300 nm 17. Manual Solutions (Preliminaries) 11 December 2012 Chapter 2 2.17 -1 where the fiber should be operated using a laser source with a maximum width of 2 nm. (a) Calculate the number V for the fiber. Is that a single mode fiber? (b) Calculates the wavelength under which the fiber becomes multimode. (c) Calculate the numerical opening. d) Calculate the maximum acceptance angle. (e) Get material dispersion and waveguide dispersion and then estimate the product of the fiber bit speed distance (BL). Solution (a) Data n1 = 1.475, n2 = 1.455, 2a = 810-6 m or = 4 m and = 1.3 m The V-number is, 2 2 2 1/ 2 V 2a n2 1/ 2 2 (4 μm) (1,468 1,464) = 2.0941 2 (1.3 μm) (b) Since V < 2.405, this is a single mode fiber. The fiber becomes multimode when V 2a (n2 n2)1/ 2,4051 2,2 n2 1/ 2 2 (4 μm)1.4682 1.4642 1/ 2 or o 1 2 ' 2.405 =1.13 m For wavelengths below 1.13 m, the fiber is a multi-mode wave guide. (c) The NA numerical aperture is 2 2 1 / 2 2 1 / 2 NA NAn1 n2 (1.468 1.464) = 0.108 (d) If max is the maximum acceptance angle, then,max arcsin' no arcsin(0.108 /1)= 6.2' so that the total acceptance angle is both(e) A = 1.3 m, from D vs , Figure 2.22, Dm 7,5 ps km-1 nm-1 , Dw 5 ps km-1 nm-1 . 1/ 2 L Dm Dw 1/ 2 = |7.55 ps km-1 nm-1 |(2 nm) = 15 ps km-1 + 10 ps km-1 = 0.025 ns km-1 The maximum bit-rate distance product is therefore BL 0.59L 0.59 = 23.6 Gb s-1 km. 1/ 2 0.025 ns km 2.13 Single-mode fiber Consider a step-index fiber with a diameter core of 9 m and refractive index of 1.4510 to 1550 nm and a normalized refraction index of 0.25% in which the fiber must be operated using a laser source with a maximum width of 3m At 1,55 m, the material and 18. Manual Solutions (Preliminaries) 11 December 2012 Chapter 2.18 waveguide dispersion coefficients of this fiber are approximately data from Dm = 15 ps km-1 nm-1 and Dw = 5 ps km-1 nm-1 . (a) Calculate the V-number for fiber. Is that a single mode fiber? (b) Calculates the wavelength under which the fiber becomes multimode. (c) Calculate the numerical opening. d) Calculate the maximum total acceptance angle. (e) Calculate the material, waveguide and chromatic dispersion per kilometer of fiber. (f) esteem the product of the distance of the bit speed (BL) of this fiber. (g) What is the maximum allowed diameter that maintains operation in single mode? (h) What is the diameter of the mode field? Solution (a) The normalized refractive index difference and n1 is given. Apply, = (n1n2)/n1 = (1.451 n2)/1.451 = 0.0025 and solve for n2 we find n2 = 1.4474. The V-number angle is given by 2 2 1/ 2 V 2a (n2 n2)1/ 2 (4,5 μm) (1,4510 1.4474) = 1.87; single mode fiber.1 2 (1,55 μm) (b) For multimodal operation we need 2 1/ 2a (2)1/ 2 (4,5 μm)(1.4510 1.4474) (e) Data, Dw = 5 ps-1 km nps km-1 nm-1 . Spectral width of laser diode (FWHM) 1/2 = 3 nm Material dispersion 1/2/L = |Dm|1/2 = (15 ps km-1 nm-1)(3 (b) = 45 ps km-1 Wave scatter 1/2/L = |Dw|1/2 = (5 ps km-1 nm) = 5 ps-1 chromatic dispersion 2,9 n 2.4 m (normal index) 11 December 2012 Chapter 2,9) BL9L 0.59 = 20 Gb s-1 km 1/ 2 (normale 1/ 2 / L) (30 1012 m1) Since it is very small, n2/n1 1 can be assumed have been convenient. The first equation can be reorganized as 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 / k [n2 b(n1 n2)] n2 (1 x) ; x b(n1 n2)/ n2 where x is small. 1 2 2 2 2 2 2 1 2 2 2 2 2 2 2 2 2 2 1 2 2 1 2 2 2 2 1 2 1 2 2 1 2 1 2 1 2 1 2 2 2 1 2 1 2 2 1 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 2 1 2 1 2 2 1 2 1 2 2.15 Group speed of the basic mode Reconsider Example 2.3.4, which has a single mode fiber with core indexes and coating of 1.4480 and 1.4400, 3 m radius, which operates at 1.5 m. Use equation b (/ k) n2; = n k[1 + b] n1 n2 to recalculate propagation constant. Change the operating wavelength to a small amount, say 0.01%, and thenthe new propagation constant . Then determine the vg group speed of the basic mode to 1.5 m, and the group delays g over 1 km fiber. How do results compare with results in example 2.3.4? For example, 2.3.4, we have b 0.3860859 , k 4188790m1 , 2c 1.2566371015 s1 n k[1 b] (1.4400) (4188790m1 (0.3860859) (1.4480400) 2 6044795m1 1.4101 1.5μm(1 1.001) 1.5015μm , b 0.3854382 Speed group 1.4800 15800 Comparison for example 2.3.4 2.0713 2.0706 %diff per 2.0706 100% 0.03% 2.16 One way of designing the fiber Sellmeier dispersion equation provides n vs for pure SiO2 and SiO2-13.5 mol.%GeO2 in Table1.2 in Ch. 1. The refractive index increases linearly with the addition 21. Manual Solutions (Preliminaries) 11 December 2012 Chapter 2 2.21 1 2 3 of GeO2 to SiO2 from 0 to 13.5 mol.%. A single step-by-step index fiber mode is required to have the following properties: NA = 0.10, core diameter of 9 m, and a pure silica coating, and operate at 1.3 m. What should be the composition of the nucleus? Solution The Sellmeier equation is A 2 A 2 A 2 A 2 A 2 n2 1 2 2 2 2 2 2 2 2 2 2 2 2 from Table1.2 in Ch.1. 1 m1 1 m1 1 x 1,47 m1Dispersion If Ng1 is the group refractive index of the base material of a step fiber, then propagation time (group delay time) of the fundamental mode is L/vg LNg1 / c Since Ng will depend on the wavelength, show that the material dispersion coefficient Dm is given approximately by d' d2 n Ld' c d2 constants using the equation Solution from Ch. 1 we know that 22. Solution Manual (Preliminary) 11 December 2012 Chapter 2 2.22 2 2 1 2 2 3 NG 2 dn g d to Differentiated from the wavelength using the ratio above between Ng and n LNg1 vg c d' L dNg1 L dn' dn L dn dd c d d d to c d2 n d2 So, Dm ' Ld' c d2 (1) From Ch. 1 we know that the equation of Sellmeier is A 2 A The 1, 294, 3700 are in m. A1 A2 1 2 3 SiO2-13.5%GeO2 We can use the Sellmeier coefficient in table 1.2 in Ch.1 to find n vs., dn/d and d2 n/d, and, from Eq. (1), Dm vs as in figure 2Q17-1. A = 1,55 m, Dm = 14 ps km-1 nm-1 Figure 2Q17-1 Dispersion materials Dm vs. Wavelength (LiveMath used). (Other mathematical programs such as Matlab can also be used.) 23. Solution Manual (Preliminary) 11 December 2012 Chapter 2 2.23 1 2 2.18 The dispersion of waveguide dispersal comes from the dependence of the propagation constant on the V number, which depends on the wavelength. It is also present when the refractive index is constant; no material dispersion. We assume that n1 and n2 are independent. Suppose it is the constant propagation of lm mode and k = 2π/in which is the free wavelength of space. Then the normalized propagation constant b and the propagation constant are related by = n2k[1 + b] (1)speed of the group is defined and given by v dc d d d d d dthat the propagation time, or the delay time of the group, of the mode is Ln2 Ln2 d(kb) (2) vg c Date the definition of V, c dk and V ka[n2 n2]1/ 2 kan (2)1/ 2 (3) d(Vb) d bkan (2)1/ 2 a (2)1/ 2 d (bk) (4) Show that dV 2 2 dV d Ln d2 (V) Dispersion index (dispersion indices) 11 December 2012 Chapter 2 2.84 V 2 D n2 1,84 (n1 n2) 1,84 (7) which simplifies the dispersion index (dispersion indices) Suppose a 1.3 m laser diode with a spectral line width of 2 nm is used to provide input light impulses. Estimates the dispersion of the waveguide per kilometer of fiber using Eqs. (6) and (8). 1.5 1 V[d2(Vb)/dV2] 0.5 0 1 2 3 V-number Figure 2.53 d2 (Vb)/dV2 vs V-number for a step index fiber. (Data extracted from W. A. Gambling et al. The Engineer of Radio and Electronics, 51, 313, 1981.) The dispersion of the waveguide of the solution occurs as a result of the dependence of the propagation constant on the number of V which depends on the wavelength. It is also present when the refractive index is constant; no material dispersion. We assume that n1 and n2 are independent. Suppose it is the constant propagation of lm mode and k = 2/where is the free wavelength of space. Thus the normalized propagation constant b is defined as, (/ k)2 n2 b 2 n2 (1) 1 2 Show that for the small normalized index difference = (n1 n2)/n1, Eq. (1) approximates to b (/ k) n2 n2 (2) giving as, = n2k[1 + b] (3) The group speed is defined and given by v dk g d di(b) 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 (6) to obtain, dn dv d(Vb) ln ' v d 2 (Vb)2 dv dv dv 2 (7) ln2 v c d2 (vb) 2 wave guide dispersion coefficient is defined as d' n d 2 (Vb)2 v (8)w Ld' c dv 2 figure 2.53 shows dependence of V[d2 (Vb) (n) 1,84 (n) 1,84 (n) 1,84 (n) 1,84 (n 2,84) 1,84 (n 2,4 c v 2,6). Suppose the 1.3 m laser diode with a spectral line width of 2 nm is used to provide input light pulses. > 1/2 = |Dw|L1/2 = (4.6 ps km-1 nm-1)(2 nm) = 9.2 ps/km 2.19 Profile Desperation Total dispersion in one mode, the step index fiber is mainly due to material dispersion and waveguide dispersion. However, there is an additional dispersion mechanism called profile dispersion resulting from the propagation constant of the fundamental mode also depending on the refractive index difference. We can see this as a change in the input wavelength. Suppose n1, n2, then depends on the wavelength. The propagation time, or delay time of the group, g per unit length is g 1/vg d / d (1/ c)(d / dk) (1) where k is the propagation constant of the free space (2/), and we used dcdk. Since it depends on n1, and V, consider g as a function n1, (so n2), and V. A change will change each of these quantities. Using the partial rule of the differential chain, 27. Solution Manual (preliminaries) 11 December 2012 Chapter 2 2.27 e e e e e 2 g n1 g V g (2) n1 e V Math is complicated but the statement in Eq. (2) is equivalent to total dispersion = material dispersion (due to ∂1/∂) + Waveguide dispersion (due to ∂V/∂) + profile dispersion (due to ∂/∂) where the last term is due to second; Although small, this is not zero. Eq's statement, too. (2) above is too simplified, but nevertheless provides a vision of the problem. The total intramodal dispersion coefficient (chromatic) Dch is then given by Dch = Dm + Dw + Dp (3) in which Dm, Dw, Dp are coefficients of material dispersion, waveguides and profiles respectively. The dispersion of the waveguide is given by Eq. (8) and (9) in question 2.18, and the profile dispersion coefficient is (very)1 , D Ng1 V d (Vb) d p di c dV 2 di d (4) (4) b in which b is the normalized propagation constant and Vd2 (Vb)/dV2 vs. V is shown in Figure 2.53, we can also use Vd2 (V. Consider awith a diameter of 8 m. The refractive and group indices of the nucleus and the coating to = 1,55 m are n1 = 1.4500, n 2 = 1.4444, Ng1 = 1.4680, Ng 2 = 1.4628, and d/d = 232 m-1 . (Note: The data values are approximate and for a fiber with silica coating and 3.6% core in germany.) Solution The total dispersion in a single step index fiber is mainly due to material dispersion and waveguide dispersion. However, there is an additional dispersion mechanism called profile dispersion resulting from the propagation constant of the fundamental mode also depending on the refractive index difference. We can see this as a change in the input wavelength. The propagation time, or the delay time of the group, g per unit length is 1 1 1 d g (1) di (1) vg c dk Dal Since it depends on n1, and V, we consider g as a function of n1, (so n2) and V. A change in in will change each of these quantities. Using the partial rule of the differential chain, 1 J. Gowar, Optical communication systems, 2nd edition (Prentice Hall, 1993.) Ch. 8 has the derivation of this equation. 28. Solution Manual (preliminary) 11 December 2012 Chapter 2 2 2.28 e e e e di 2 p 2 g n1 g V g (2) n1 . V . Mathematics is complicated but the statement in Eq. (2) is equivalent to total dispersion = material dispersion (due to n1/) + waveguide dispersion (due to V/) + profile dispersion (due to /) where the last term is due to second; although small this is not zero. Also the above statement in Eq. (2) it issimplified, but nevertheless provides a look at the problem. The total intramodal dispersion coefficient (chromatic) Dch is then given by Dch = Dm + Dw + Dp (3) where Dm, Dw, Dp are material, waveguide and profile profilecoefficients respectively. The dispersion of the waveguide is given by Eq. (8) in demand 2.6 and the profile dispersion coefficient is (very) approximately, D Ng1 V d (Vb) d p di c dV 2 di d (4) dove where b is the normalized propagation constant and Vd2 (Vb)/dV2 vs. V is shown in Figure 2.53 Consider a fiber with a diameter of 8 m. Refraction and refractive indexes of the nucleus and coating to = 1.55 m are n1 = 1.4504, n 2 = 1.4450, Ng1 = 1.4676, Ng 2 = 1.4625 d/d = 161 m-1. 2 1/37 V 2a n2 1/ 2 2(4 μm) (1.4504 1.4450) = 2.031 2 (1.55 μm) and From the graph N ' d2 Vb d D 'g1 V (1.4676 0.50161m1 c dV 2 d ' 3 108 m s1 Dp = 3.8 10-7 m-1 or 0.38 ps km-1 nm-1 waveguide dispersion: Dw) 1.984 c(2a)2 2n 1.984(1500 109 m2) (3 108 106 m-1 Dw 5.6 ps km-1 nm-1 Profile dispersion is more than 10 times smaller than waveguide dispersion. 29. Solution Manual (Preliminary) 11 December 2012 Chapter 2 2 2.29 e di di di di di di di di di di di di di di di di di di di di di di 2.20 Dispersion coefficient zero dispersion Since the spread in group lag along a fiber depends on the , the source line width can expand as a Taylor series in . Consider expansion to = 0 where Dch = 0. The first term with would be d /d as a coefficient that is Dch, and to 0 this will be zero; but not the second term with (which has a differential, d2 /d or dDch/d. Thus, the 0 dispersion would be controlled by the S0 slope of Dch vs. Turn to 0. Show that chromatic dispersion at 0 is re L 2 S0 () 2 A single mode fiber has a zero dispersion to 0 = 1310 nm, S0 gradient = 0.090 ps nm2 km. What is the dispersion for a laser with = 1.5 nm? What would you control the dispersion? Solution Consider Taylor expansion for , wavelength function, about its center around, say 0,change we changefrom For convenience we can absolute value of 0 as zero since we are only interested in the diffusion. Then, Taylor's expansion gives, ,f () ' d ()) 1 d 2 ' ()2 ds 2 ' 2! d2 d 0 1 ()2 0 1 ()2 1 D ()2 2! d2 2! dt d ' 2! dt ch L 2 1 km ' -2 -1 2 S0 () 2 km What would be the dispersion, maximum bit speed and optical bandwidth for this fiber on a 200 km long optical connection if the only dispersion mechanism was PMD? Dispersion DPMD L1/ 2 0.05ps km1/ 2 (200km)1/ 2 0.707ps Bit rate B 0.59 0.59 8.35Gb s-1 0.707ps Optical bandwidth 0.75B (0.75)(8.35 Gbs1) 6.26 GHz 30. The chromatic dispersion is zero at 1315 nm, and the gradient is 0.092 ps nm-2 km-1. The PMD coefficient is 0.05 ps km-1/2 . Calculate the total dispersion of 100 km if the fiber is operated at 1315 nm and the source is a laser diode with a line width (FWHM) = 1 nm. What should be the line width of the laser source so that more than 100 km, the chromatic dispersion is the same as the PMD? Dispersion of solution polarization mode for L = 100 km is di PMD DPMD L1/ 2 = 0.05 di 100 ps = 0.5 ps We need chromatic dispersion to 0, where chromatic dispersion Dch = 0. For L = 100 km, the chromatic dispersion is L S ()2 ch 20 2 = 1000.092(1)2 /2 =ps 2 rms di PMD ch = 4.63 ps The condition for PMD ch is di 2DPMD S L1/ 2 = 0.33 nm 2.23 scatter compensation Calculate total dispersion and general generaldispersion coefficient when a transmission fiber of 900 km with Dch = +15 ps nm-1 km-1 is spliced to a compensation fiber that is 100 km long and has Dch = 110 ps nm-1 km-1 . What is the general coefficient of effective dispersion of this combined fiber system? Assuming that the spectral width of the input light is 1 nm. Solution Using Eq. (2.6.1) with = 1 nm, we can find total dispersion = (D1L1 + D2L2) di = [(+15 ps nm-1 km)(900 km) + (110 ps nm-1 km-1)(100 km))](1 nm) = 2.500 ps nm-1 km. The net or effective dispersion coefficient can be found by = DnetL, Dnet = /(L = (2,500 ps)/[(1000 km)(1 nm)] = 2.5 ps nm-1 km-1 2.24 Closing diameter A comparison of two index steps, one SMF and the other MMF diameter shows that the SMF has a core diameter of 9 m but a coating diameter of 125 m, while the MMF Discuss why the producer chose those values. Solution For single mode fiber, the diameter of the small core is to ensure that the number of V is below the cutoff value for the operation of the singe mode for commonly used wavelengths 1.1 m and 1.5 m. The largest total 31. Manual Solutions (Preliminary) 11 December 2012 Chapter 2 2.31 ' ' ' di metro metro metro metrodiameter is to ensure that there is enough coating to limit the loss of light that penetrates the coating as an evanescent wave. For multimode fibers, the size of the larger nucleus allows multiple ways of propagating in the fiber and therefore the spectral width is not critical. In addition, the larger diameter is in a larger acceptance angle. Thus, LEDs, which are cheaper and easier to use than lasers, are highly suitable. The total diameter of the core and the coating is the same because in industry it is convenient to standardize the equipment and the minor lossescould accumulate from the light that evades from the coating no matter so much beyond the shorter distances for multimodal fibers – they are short algae fibers. 2.25 Graded Graded Index Fiberoptimum grade index fiber with a diameter of 30 m and a refractive index of 1.4740 at the core and a refractive index of coating of 1.4530 Find the number of modes at 1300 nm operation. What is its NA to the fiber axis, and its NA effective? Suppose the fiber is coupled with a laser emitter diodes at 1300 nm and a spectral line width (FWHM) of 3 nm. The material dispersion coefficient at this wavelength is about 5 ps km-1 nm-1 . Calculates the total dispersion and estimates the product of the fiber bit speed distance. How do you compare with the performance of a multimodal fiber with the same nucleus, and n1 and n2? What would be total dispersion and maximum bit speed if a spectral width LED source (FWHM) 1/2 80 nm is used? 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 The corresponding B for 1 km would be about 13 Mb With LED excitation, again assuming a form of Gaussian output light pulse, the material dispersion rms is m (0.425) m(1/ 2) (0.425)LDm 1/ 2 0.425)(1000 m)(5 ps ns1 km1)(80 nm) = 0.17 ns Total dispersion is 22 2 2 2 2 2 totale totalm ' 0.029 0.17 = 0.172 ns so that B = 0.25/totale = 1.45 Gb The effect of material dispersion now dominates intermodal dispersion. 2.26 Graded Fiber Index Consider an index fiber classified with a diameter of 62.5 m and a refractive index of 1.474 at the core and a refractive index of coating of 1.453. Suppose we use a laser diode emitter with a spectral line width of 3 nm FWHM to transmit along this fiber to a wavelength of 1300 nm. Calculate, total dispersion and estimate the bit-rate fiber distance product. The material dispersion coefficient Dm at 1300 nm is 7.5 ps nm-1 km-1 . How do you compare with the performance of a multimodal fiber with the same nucleus, and n1 and n2? Solution Normalized refractive index = (n1n2)/n1 = (1.4741.453)/1.47474 = 0.01425 Modular dispersion for 1 km of classified index fiber is Ln1 2 (1000)(1.474) 2 = 2.910-11 s or 0.029 ns.intermode di 20 Material dispersion is La 3c 20 (0.01425) 3(3 108) m(1/ 2) LDm 1/ 2 (1000 m)(7.5 ps ns1 km1)(3 nm) = 0.025 If it were a step-index multimodal fiber with the same n1 and n2, the rms dispersion would be approximately n1 n2 1.474 1.453 L c 3108 m s-1 33. Manual Solutions (Preliminary) 11 December 2012 Chapter 2 2.33 di di di di di) 1 e 1 -1 2 -1 T = 70 ps m-1 or 70 ns per km Mb s-1 km (only one estimate!) The corresponding B for 1 km would be about 13 Mb s-1 . 2.27 Graded Fiber Index A standard grade index fiber from a particular fiber manufacturer has a core diameter of 62.5 m, coating diameter of 125 m, a NA of 0.275. The nucleus refractive index n1 is 1.4555. The manufacturer cites the minimum optical bandwidth × distance200 MHzkm at 850 nm and 500 MHzkm at 1300 nm. Take that a laser should be used with this fiber and the laser line width = 1.5 nm. What are the corresponding scatter values? What kind of dispersion do you think? Does the classified index fiber have the ideal index profile? (Stay your assumptions). What is the optical connection distance for operation at 1 Gbs-1 at 850 and 1300 nm Solution We are given the NA = 0.275 numerical opening. The total dispersion of this is the maximum NA 1 n2 NA2 2 1.45552 0.2752 2 1.4293 n1 n2 1.4593 130018 n1 1.4555 We can now calculate intermodal dispersion n1 2 (1.4555)(0.018)2 intermodal . 20 20 3c 20 3(3105 km s1) 45.43ps km Solution Manual (preliminaries) 11 December 2012 Chapter 2 2.34 ' ' ' ' ' N ' 2(1) 2(1 0.018) 1.96 Range is close to 2 so this is close to the optimal profile index. 2.28 Graded Index Fiber and Optimal Dispersion The theory and equations of indexed fibers tend to be quite complicated. If it is the profile index then the intermodal dispersion rms is given by 2 Ln ' 1/ 21 del 2c 1 3 2 (1) (1) 4c c (1) ' 16c22 (1) 2 1/ 2 c2 1 2 1 2 1 2 1 (5 2) where c1 and c2 are given by ' n1 d 2; c 3 2 2 ottimale ottimale ottimale 2The minimum. (Consider plotting on a logarithmic axis.) Compare the minimum and the excellent , with the relative expressions in §2.8 Find the percentage change in for a 10× increase in . What's your conclusion? Solution 2 R. Olshansky and D. Keck, Appl. Opt, 15, 483, 1976. 35. Solution Manual (Preliminary) 11 December 2012 Chapter 2 2 2.35 di di di Dal Dal Dal From Figure 2Q28-1 0 = 2.04 Equation (3) gives the same value 0 = 2.040 From Figure 2Q28-1 intermode/L = 31.87 ps km-1 Consider Eq. (2.8.4) in §2.8, intermode n1 2 = 31.93 ps km-1 . L 20 3c From chart 2Q28-1, a change of 3.4% leads to 10 times increase of dispersion. It is therefore important to check the refractive profile. Figure 2Q28-1 2.29 GRIN rod lens Figure 2.32 shows the classified index rod lenses (GRIN). (a) As represented by Figure 2.32(a) using two converging conventional lenses. What am I O and O? (b) As represented by Figure 2.32(b) using a conventional convergent lens. What's O? (c) Ray paths for a GRIN rod with a step between 0.25P and 0.5P from O to the center of the face. Where's O? (d) What use is the GRIN 0.23P auction objective in figure 2.32(c?) Figure 2.32 Graded Index (GRIN) rod lenses of different fields. (a) Point O is located on the center of the face of the rod and the lens concentrates the rays on O' on the center of the opposite face. (b) The rays from O on the center of the front of the auction are shocked out. (c) Or is slightly far from the face of the rod and the rays are upset out. Solution (a) and (b) 36. Solution Manual (Preliminary) 11 December 2012 Chapter 2 2 2.36 di Figure Figure 2Q29-1: (a) The bending of the beam from O to O using a GRIN bar can be reached in an equivalent way using two converging lenses. O and O are the focal points of the lenses (approximately.) (Schematic only.) b) The collimation of the rays from a point source on the face of a GRIN rod can be equivalent to that of a single convergent lens whosefocal is 0.25P and andis the focal point. (Schematic only). (c) Considering a GRIN rod with 0.4P Figure 2Q29-2: Ray routes in a GRIN rod which has a step between 0.25P to 0.5P. (Schematic only.) (d) Since the O point should not be right on the face of the GRIN bar, it can be used to bridge a point source O bringing the rod sufficiently close to O; a fixed annular spacer may be contacted. 2.30 Optical fibres Consider the production of optical fibres and materials used. (a) What factors would reduce dispersion? b) What factors would reduce attenuation? Possible answers (a) It is essential to check the profile of the refractive index, the radius of the nucleus and to minimize the variations of the refractive index due to variations of doping. b) Minimize impurities. Reduce dispersion by reducing density and therefore the refractive index n fluctuations (can not be easily possible). Use a glass material with a lower glass transition temperature so that frozen n-variations are smaller. 2.31 attenuation A laser emitter with a 2 mW power is used to send optical signals along an optical fiber connection of length 170 km. Suppose all the light was thrown into the fiber. The fiber is cited as 37. Manual Solutions (Preliminary) 11 December 2012 Chapter 2.37 . . . . 1 with 0.5 dB/km attenuation. What is the output power from the optical connection that a photodetector should be able to detect? Pout Pin exp(L) solution where dB 0.5dB km 0.115 km1 4.34 so 4.34 Pout 2 mWexp(0.115 km1 170 km) 6.24 pW 2.32 Method of cutting the attenuation measurement The Cut-back method is a destructive measurement technique to determine the attenuation of a fiber. The first partconsists in measuring the optical power pfar that comes out from the fiber to the extreme as shown in figure 2.54 then, in the second part, keeping all thefiber is cut near the launch or end of the source. The output power Pnear is measured at the next end by the short cutting fiber. The attenuation is then given by = (10/L)log(Pfar/Pnear) in which L is the separation of the measuring points, the length of the cutting fiber, and is in dB per unit length. The short cut fiber output Pnear in the second measure is actually the entry into the fiber under test in the first experiment. Usually a mode massacrer (mode stripper) is used for multimode fibers before the entrance. The output of power from a particular fiber is measured to be 13 nW. Then, 10 km of fiber is cut off and the output of power is measured again and is located at 43 nW. What is the attenuation of the fiber? Figure 2.54 Illustration of the cutting-back method to measure fiber attenuation. S is an optical source and D is a photodetector 38. Solution Manual (Preliminary) 11 December 2012 Chapter 2 2.38 di di e R R Solution = (10/L)log(Pfar/Pnear) = (10/10 km) log (10/43) = 0,63 dB km-1 2.33 Intrinsic Loss (a) Consider a standard single mode fiber with a NA of 0.14. What is its attenuation at 1625 and 1490 nm? How do we compare the attenuation quotes for Corning SMF-28e+, 0.200.23 dB km-1 at 1625 nm and 0.21 0.24 dB km-1 at 1490 nm? (b) Consider an index fiber classified with a NA of 0.275. What do you expect for its attenuation at 850 nm and 1300 nm? How do you compare your calculations with maximum values cited by 2.9 dB km-1 to 850 nm and 0.6 dB km-1 to 1300 nm for 62.5 m grade indices? The actual values would be less. Solution (a) When wavelength is 1625 nm, FIR Aexp B / B 11 11 ' 48.5 -1 FIR Aexp 7.810 exp 0.085dB km 1.625' At 0.63 2.06NA 0.63 2.06 0.14 0.918dB km-1 µm4 1 4 to AR aR 4 0.918dB km µm 1.625µm4 0.132 dB km1 When wavelength is 1490 nm B ' 11 ' 48.5 -1 FIR Aexp 7.810 exp 0.0057 dB km 1.490' To 0.63 2.06NA 0.630.14 0.918dB km-1 µm4 1 4 4AR 0.918dB km µm 0.1863dB km1 total 4 FIR 1.490µm4 0.0057 0.1863 0.192dB km-1 (b) 1300 Rayleigh scatter AR = 0.63 + 1.75×NA = 0.63 + 1.75×0.275 = 1.111 dB km-1 m4 A 850 nm and 1300 nm FIR A 850 nm The expression for attenuation R in a single component glass such as silica due to Rayleigh's dispersion is approximately given by two sets of different equations in literature3 , 83 R n 34 p2 k T and 83 R (n 34 1)2 T kBTf glass in which is the free wavelength of space, n is the refractive index to the wavelength of interest, is the glass interchangeability The fiber is drawn at high temperatures and, when the fiber cools, the temperature drops sufficiently for atomic movements to be so slow that the structure becomes essentially "freeze" and thus remains at room temperature. Thus, Tf marks the temperature below which the liquid structure is frozen and therefore density fluctuations are frozen also in the glass structure. Use these two equations and calculate attenuation in dB/km due to Rayleigh dispersed around the window = 1.55 m as pure silica (SiO2) has the following properties: Tf 1180°C; T 710-11 m2 N-1 (at high temperatures); n 1.45 to 1,55 m, p = 0.28. The lowest attenuation reported around this wavelength is about 0.14 dB/km.Is that your conclusion? Solution 83 -1 -1 R n 34 p T kBTf = 0.0308 km or 4.34×0.0308 = 0.13 dB km 83 R (n 34 1)2 k T = 0.0245 km-1 or 4.34×0.0245 = 0.11 dB km-1 The first equation seems to be the closest to the experimental value. However, note that the attenuation reported also has a contribution from the fundamental absorption of the IR. FIR Aexp B / , A = 7.81×10 dB km-1; B= 48.5 m gives FIR = 0.02 dB km-1 . Thus, the addition of FIR to R gives first equation + attenuation FIR = 0.13 + 0.02 = 0.015 dB km-1 Second equation + attenuation FIR = 0.11 + 0.02 = 0.013 dB km-1 3 For example, R. Olshansky, Rev. Mod. Phases 51, 341, 1979. 40. Solution Manual (Preliminary) 11 December 2012 Chapter 2 2.40 di di di . . sperimentale Experimental value is exactly between. 2.35 Bending Loss Bending losses always increase with the diameter of the mode field (MFD). Since the MFD increases to decrease V, 2w 2×2.6a/V, the smaller V fibers have higher bending losses. As does the loss of curvature against the radius of curvature R behavior resembles a semi-logarithmic plot (as in Figure 2.39(a) for two values of V-number V1 and V2 if V2 > V1. It turns out that for a single mode fiber with a cut wavelength c = 1180 nm, which operates at 1300 nm, the loss of microbending reaches 1 dB m-1 when the curve radius is about 6 mm per = 0.00825, 12 mm per = 0.00550, and 35 mm per = 0.00275. Explain these results. Solution We expect the loss of bending against. R on a semilogarithmic plot to be as in Figure 2Q35-1 (schematic) Figure 2Q35-1 The loss of microbending decreases sharply with the radius of R. curve (only schematic.) From the figure, given = 1, R increases from R1 to R2 when V decreases from V1 to V2. R expected with V (1) Equivalently to a R = R1 with V (2)e We can generalize by noting that the depth of penetration into the coating 1/V. R predicted with (3) con Equivalentlya r = r1 with (4) eqs. (3) and (4) correspond to the general statement that the loss of microbending worsens when penetration inincreases; intuitively correct according to Figure 2.32.i Experiments show that for a given = 1, R increases with decrease. Observation R with (5) di Consider penetration depth in a second medium (Example 2.1.3), 41. Thus, it increases with decrease. So, from Eqs. (3) and (6), we expect R planned with (7) So Eq, (7) agrees with observation in Eq. (5). NOTE If we're going against it. A on a log-log plot, we will find the line in Figure 2Q35-2, that is Rx , x = 0,62. Very roughly, from theoretical considerations, we expect R , R exp di 3 / 2 □ (8) Rc dove where Rc is a constant ("a type of critical radius of constant") which is proportional to . Thus, taking logs, ln 3 / 2 R constant (9) We are interested in behavior R to a constant . We can accumulate the constant in ln and get, R2 / 3 (10) As shown in figure 2Q35 0.01 1 10 100 y = 0.0255x-0.625 R2 = 0.9993 0.001 R (mm) Figure 2Q35-2 The ratio between and the radius of bending R for a given amount of bending loss. 42. Solution Manual (Preliminary) 11 December 2012 Chapter 2 2.42 di di di di di di di . 2.36 Reduction of mud loss Consider the curve loss measures listed in Table 2.8 for four types of fiber difference. The trench fibers have a trench placed in the coating where the refractive index is lowered as shown in Figure 2.39 The nanoengineering fiber is shown in Figure 2.55. There is a region ring in the lining where there are nanoscale voids filled with gas. (They are introduced during manufacture.) A vacuum in the ring has a circular cross section but has a length along the fiber that can be a few meters. These voids occupy a volume in the ring that is only 1 - 10%. Trams bending loss(on linear log and R scale) and adapt data to micobend = Aexp(R/Rc) and find A and Rc. What's your conclusion? Suppose we set our maximum bending loss acceptable to 0.1 dB/turn in installation (the current goal is to bring the bending loss below 0.1 dB/turn). What are the curved rays allowed for each turn? Table 2.8 R of the mud radius in mm, in dB/turn. Data over 1.55 - 1.65 m. (Note, data used by a number of sources: (a) M.-J. Li et al. J. Light Wave Technol., 27, 376, 2009; (b) K. Himeno et al, J. Light Wave Technol., 23, 3494, 2005; (c) L.- A. de Montmorillon, et al. "Bend-Optimized G.652D Proceedings of the 55th IWCS/Fogine R mm dB/turn □ R mm . dB/turn. R mm □ dB/turn□ 5.0 15.0 7.50 0.354 5.0 0.178 5.0 0.031 7.0 4.00 10.0 0.135 7.5 0.0619 7.5 0.0081 10.0 0.611 15.0 0.020 10.0 0.0162 10.0 0.0030 12.5 0.124 15 0.00092 15 0.00018 16.0 0.0105 17.540 Solution 43 Manual Solutions (Preliminary) 11 December 2012 Chapter 2 2.43 . □ . . . . y = 418.95e-0.659x y = 6.241e-0.383x y = 0.4079e-0.51x y = 2.971e-0.533x 1 dB/turn Bend Losses 100 10 1 0.1 Standard SMF Trechen Expoered 2MF. Adjustment per turn as a function of the curve radius For a bending loss of 0.1 dB/turn, the curved rays allowed are (very approximately) Standard SMF, 13 mm; trench 1, 10 mm; trench 2, 6 mm; nanoengineering, 3 mm. 2.37 Microbending loss The loss of microbending B depends on the characteristics of the fiber and wavelength. We will calculate approximately data various fiber parameters using the microbending loss equation of single mode fiber (D. Marcuse, J. Op. Soc. Am., 66, 216, 1976 1/ 2 3 R1/ 2 exp(2 RB/ 2 V 2 K (a) 2) 3 2 where R is the bending radius, a = fiber radius, is the propagation constant, determined by b, normalized propagation constant, which is related to V, = n2k[1 + b]; k = 2/ is the free-space wave vector; = [2 n2 2 k2]; = [1 2 k2], and K1(x) the available function is a normal propagation constant b can be found by b = (1.14280.996V- 1)2 . Consider a single mode fiber with n1 = 1.450, n2 = 1.446, 2a (diameter) = 3.9 m. R = 633 nm and 790 nm from R = 2 mm to 15 mm. Figure 2.56 shows experimental results on a SMF that has the same properties as the fiber above. What's your conclusion? (You may want to compare your calculations with the experiments of A.J. Harris and P.F. Castle, IEEE J. Light Wave Technol., LT4, 34, 1986). 5, 5, 5, 5 V 2a (n2 n2)1/ 2 □ 2(3.9 µm)(1.4502 1.4462)1/ 2 = 2.08; 2n2 1 2 (0.633 µm) 45.these values in 1/ 2 3 r1/ 2 exp(2 rb rb/ 2 V 2 K (a) 2) 3 2 to be found (2.08103)R1/ 2 exp(R)B 0.00089 which is traced on the RHS of Figure 2Q37-1. Figure 2Q37-1 Bending loss B vs. R curve radius (LiveMath used.) The results reasonably compare with the experiments in Figure 2.56 given the approximate nature of the theory. Note that the calculated attenuation is per meter (for 1 meter) while the attenuation in Figure 2.56 is for a fiber of 10 cm, so that for a 1 m fiber, the observed attenuation will be 10 times higher. 2.38 Fibra Bragg grater A fiber silica based FBG is necessary to operate at 850 nm. What should be the periodicity of grater? If the width of the index n is 2×10-5 and the total length of the FBG is 5 mm, what are the maximum reflectance on the wavelength of Bragg and the bandwidth of the FBG? It is assumed that the effective refractive index is 1.460. What are the reflectance and bandwidth n is 2×10-4? Solution B Using the equation for Bragg wavelength B 2n you can get . n = 291.1 nm. The results of 2 additional calculations per n = 2×10-5 and 2×10-4 are collected in Table. FBG #1 FBG #2 n 2×10-5 1×10-4 46. Solutions manual (preliminaries) 11 December 2012 Chapter 2 2.46 e e e e e e 1 2 2 (1/m) 73.92 739.2 L 0.37 3.7 Grating is weak strong R tanh2 (L) 0.125 0.998 2 4B , nmstrong n NA 0.47 The L parameter for FBG#1 with n = 2×10-5 is equal to 0.37 which is a weak gratification. The L parameter for FBG#2 with n = 2×10-4 is equal to 3.7 which is a strong gratification. 2.39 Fiber Bragg Grid Array Sensor Consider an array of FBG sensors embedded in a silica fiber that is used to measure tension in various locations on an object. Two nearby sensors have a periodic gratification of 1 = 534.5 nm and 2 = 539.7 nm. The effective refractive index is 1.450 and the photoelastic coefficient is 0.22. What is the maximum voltage that can be measured by assuming that (a) only one ofis tense; (b) when the sensors are filtered opposite? What is the main problem of this array of sensors? What is the fracture tension if the fiber fractures approximately to an applied stress of 700 MPa and the elastic module is 70 GPa? What's your conclusion? Initially the Bragg wavelengths of two sensors are B1 2n1 = 1550.05 nm and B2 2n2 = 1565.13 nm, respectively. When the second sensor is extended its effective refraction index changes due to photoelastic effect and there is also a change in the period, both leading to ,(1 1 n2 p)B2 B2 2 and B2 moving to B1 . (a) The separation between wavelengths Bragg is B = B2 B1 = 1565.13 – 1550.05 = 15.08 nm 47. Manual Solutions (Preliminary) 11 December 2012 Chapter 2 2.47 . . . . 1 1 1 2 2 (b) Consider the sensors deformed in opposite directions. The separation between the wavelengths of Bragg is still B2 B1 = 1565.13 – 1550.05 = 15.08 nm. Note that B2 B1 = 2n(2 2) The shift due to the voltage is now B = B2 1 2 n pe B11 2 n pe 2n(1 2)1 2 n pe That must be B2 B1 so that 2n(della) 2n(□))1 1 n2 p2 2 2 2 and 2 = 0.0063 or 0.63% (about half the value above).. (.)1 1 n2 p1 2 2 and The main problem is the precise compensation of the temperature. Manual of solutions for Optoelectronics and the principles and photographic practices 2nd edition of Kasap Download completely clear (without formatting errors) at: principles-e-practice-2nd-edition-by-kasap/ People also search: optoelectronics & photoand photonic principles and practices pdf optoelectronics and andprinciples and practices kasap pdf optoelectronics and photonics principles and practices 2nd edition optoelectronic and photonic solution principles and practices pdf download free optoelectronic and photonic kasap pdf optoelectronic and photonic 2nd edition pdf optoelectronic and photonic principles and practices 1st edition optoelectronics and photonics principles and practices second edition s.o.kasap. optoelectronics and photonics principles and practices second edition pdf. solutions manual to optoelectronics and photonics principles and practices second edition

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